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THESIS

APPLICATION OF THE TERRESTAR SATELLITE CONSTELLATION TO THE GLOBAL INITIATIVE FOR TRACKING SPECIAL AND NONPROLIFERATION MATERIAL

by

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September 2011

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In an era distinguished by innovative communication technologies capable of linking with geosynchronous satellites, while being small enough to fit into a pocket of clothing, the modern battlefield commander and warfighter can know the precise location of surrounding friendly forces. This concept of communication involving satellites provides for a new tier of situational awareness in combat and noncombat environments, dating as far back as the Persian Gulf War. This tool altered the command and control element by improving the knowledge and certainty that this capability provided. Recent studies and experiments have demonstrated the applicability of these military systems to civil service as well. Space based situational awareness provide capabilities such as continuous over-the-horizon communications and position reporting of friendly assets. These capabilities have been available since the Persian Gulf War. System limitations include a lack of real-time image, terrain masking, and security.

Until recently, the devices used for Friendly Force Tracking have been devices that rely on National Technical Means. However, the recent trend is to use commercially available technology to enable tracking of both friendly and enemy forces. This technology ranges from the use of GPS equipped cell phones to satellites in LEO such as Iridium and GlobalStar. Terrestar is a new company specializing in space technology and wireless communication devices. Additionally, TerreStar wireless communication devices are designed to use both cellular and satellite networks. This feature provides a redundant tracking method not otherwise available. This study includes an investigation into Terrestar tracking devices used to locate and monitor the position and movement of friendly forces.

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

AT&T	Refers to the company AT&T
BFT	Blue Force Tracking
BFT-1	Blue Force Tracking Version One
C2	Command and Control
CENETIX	Center for Network Innovation and Excellence
CDF	California Department of Forestry and Fire Protection
COP	Common Operating Picture
DOD	Department of Defense
EPLRS	Enhanced Position Location Reporting System
ε(Epsilon)	Look Angle
GBBF	Ground Based Beam Forming
GEO	Geostationary Earth Orbit or Geosynchronous Earth Orbit
GIS	Geographic Information System
GPS	Global Position System
GSM	Global System for Mobile Communications
HEO	Highly Elliptical Orbit
IP	Internet Protocol
ITT	ITT Corporation
JFT	Joint Force Tracking
λ(Lambda)	Earth Central Angle
LED	Light-Emitting diode
LEO	Low Earth Orbit
LOS	Line of Sight
MEO	Medium Earth Orbit
MIO	Maritime Interdiction Operations
MSS	Mobile Satellite Service
NAD	North American Datum
NGVD	National Geodetic Vertical Datum
NPS	Naval Postgraduate School
η(Nu)	Nadir Angle

OODA	Observe, Orient, Decide, Acting
ORS	Operationally Responsive Space
OTH	Over-the-Horizon
OV	Operational View
PLI	Position Location Information
ρ(Rho)	Angular Radius of the Earth
RFT	Red Force Tracking
RFID	Radio Frequency Identification
SA	Situational Awareness
SAR	Search and Rescue
SINCGARS	Single-Channel Ground/Air Radio System
SNR	Signal-to-Noise Ratio
SUV	Sport Utility Vehicle
TACSAT	Tactical Satellite
TNT	Tactical Network Testbed
TOC	Tactical Operations Centers
UHF	Ultra High Frequency
UK	United Kingdom
U.S.	United States
USA	United States Army
USB	Universal Serial Bus
USAF	United States Air Force
USGS	United States Geological Survey
USMC	United States Marine Corps
VHF	Very High Frequency

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I. INTRODUCTION

A. BACKGROUND

This age of modern technology enables the battlefield commander and warfighter to know the precise location of his or her friendly Blue forces in addition to hostile Red forces using space-based satellite tracking systems. This concept, also called Joint Force Tracking, provides for a new tier of situational awareness in combat and noncombat environments. The capability to track the precise location of forces was first used during the Persian Gulf War when battlefield commanders used space-based systems to plan and coordinate missions. This tool changed the command and control element with the knowledge and certainty that this capability provided. Studies and experiments conducted in the past 10 years have moved to expand this capability provided to battlefield commanders into nonmilitary applications. Such applications may extend to civil service personnel such as police agencies and fire departments in the United States and abroad.

B. PURPOSE

In order to determine how the most accurate and necessary BFT information can be provided to the user, an investigation of current and legacy tracking systems was conducted. This investigation evaluated the capabilities of the TerreStar constellation for real-time situational awareness to include the following: Blue/Red Force Tracking (BFT/RFT), Search and Rescue (SAR) operations and special events bounded by hazards in and around urban canyon locations and underserviced areas traditionally covered by Global Position System-based tracking systems (GPS) as well as the maritime environment such as harbor facilities. Additionally, this study will include research into surveillance techniques that enable tagging a small craft or vehicle that is carrying illicit/nonproliferated materials, locating it, and tracking its global movement. Lastly, this research will include an evaluation of the effects of cyber distortion on tagging and tracking.

C. SCOPE

This research is directed toward the Department of Defense space professional community, intelligence community, and special operations community. This study will focus primarily on developing an understanding of Blue Force Tracking systems and theories. The intent is to expose the readers to the challenges with regard to Blue Force Tracking, determine optimal approaches to GPS utilization, provide resources for further education, and prepare someone for future assignments at either the tactical or operational level using Blue Force Tracking.

D. METHODOLOGY OF RESEARCH

The majority of the material used for this research originated from articles, studies, experiments, and books involving Blue Force Tracking, the Tactical Network Testbed, and Maritime Interdiction Operations. Additionally, subject matter experts and professors were consulted to establish a basis for background information.

II. LEGACY BLUE FORCE TRACKING SYSTEMS

A. DEFINITION OF BLUE FORCE TRACKING

Blue Force Tracking is a term originating from the United States military used to indicate a Global Positioning Satellite-enabled system that is capable of providing location information about friendly military forces to both combatant commanders and other forces. The Blue Force Tracking system consists of various ground components such as handheld tracking devices, ground control stations, computers, satellite antennas, and mapping software. The Blue Force Tracking system also consists of a complex space element involving sophisticated satellites located in various orbits around the Earth capable of providing global coverage (Imagery-Intelligence, 2010).

1. History of Blue Force Tracking

Before new tracking systems can be explored, the history of legacy Blue and Red Force Tracking systems should be understood to include how battlefield commanders have benefited from this system. Blue Force Tracking is a modern concept that enables battlefield commanders to increase overall situational awareness within a geographic area, enhances the command and control structure, and reduces occurrences of friendly fire. Current users of the system include the United States Army, the United States Marine Corps, the United States Air Force, and military forces of the United Kingdom. Version 1 Blue Force Trackers provided significant improvements to situational awareness as early as 1990 during the Persian Gulf War in Iraq (Citizendium, 2011).

Prior to 1990, positional information was transmitted from user to user via line-of-sight radio transmission and plotted manually. During the 1990s, the United States Army used the very first Blue Force Tracking system known as BFT-1, which provided the first steps in automating the transmission of positional-type information. In its original configuration, BFT-1 consisted of a battle-management system with application software running on computer terminals linked directly to GPS satellite receivers. These computer terminals were established in Tactical Operations Centers, or TOCs, at battalion and brigade levels, and on weapons platforms and combat vehicles as, illustrated in Figure 1 (Jane's Information Group, 2008).

Figure 1. Blue Force Tracking Computer (From [Defense Industry Daily, 2006])

In addition to formatted command and control messages, these computer terminals were intended to transmit and receive electronic map-based situational awareness data on both Blue and Red dispositions based on visual observations and automatic GPS-derived position reports with each other using a tactical Internet. A two-tier terrestrial radio network consisting of a variety of transmitting systems enabled GPS-derived position reports. These transmitting systems include a modified version of the Single-Channel Ground/Air Radio System, or SINCGARS, which is produced by the company known as ITT. Other transmitting systems include Very High Frequency (VHF) radios produced by Raytheon, Enhanced Position Location Reporting System (EPLRS) and Ultra High Frequency data radios, or UHF (Jane's Information Group, 2008).

2. Relevance of Blue Force Tracking

The concept of Blue Force Tracking is still in its infancy stages in terms of its implementations. This system can be used by nongovernment agencies as well as government agencies including military and nonmilitary such as police and fire departments. The system can be used to track personnel, equipment, and possibly nonproliferated items such as nuclear or chemical weapons. Currently, the majority of utilization rests with military battlefield commanders. The ability of a battlefield commander to track both blue and red forces via a satellite network, while using that data to plan and coordinate movement of military personnel and equipment provides an entirely new tier of situational awareness leading to changes in the command and control structure and network, which could ultimately result in fewer incidents of friendly fire.

a. Situational Awareness

Situational awareness, or SA, is one's measurement of the perceived environmental elements within a volume of time and space in comparison with reality. Maintaining a high sense of situational awareness involves obtaining a grasp of the events that are occurring in the area in question. One must also understand how information, events, and one's own actions will impact any goals and objectives within this given volume of time and space. Complete or partial lack of situational awareness has been identified as one of the primary causal factors involving accidents accredited to human error during war fighting operations. In this respect, situational awareness becomes increasingly vital in instances where information flow is considerably high. In some occupations, maintaining accurate and precise situational awareness is absolutely essential in areas where technological and situational complexity on the human decision-maker is a concern. In many circumstances, situational awareness has been renowned as a significant method for lucrative decision-making across a broad range of complex and dynamic systems (Burton, 2007).

On a field of battle, combatant commanders may seek an elevated level of situational awareness which can be provided to leaders and planners via technological means. Blue and Red Force Tracking systems can provide the information necessary to manipulate forces around hazards more quickly and safely than the enemy. Additionally, Red Force Tracking systems have a mechanism for reporting the locations of enemy forces and other information concerning the battlefield such as the location of mine fields or other obstacles (Burton, 2007).

b. Command and Control Structure

Command and control, or C2, in a military organization is generally regarded as the employment of authority by a properly designated commanding officer over designated military forces in the accomplishment of a mission. This concept follows the process of observing, orienting, deciding, and acting, which is known as the OODA loop, as illustrated in Figure 2. The military commander can use Blue and Red Force Tracking systems to observe enemy positions and obstacles before orienting Blue forces on the objective. Once the decision is made, the best course of action can be accomplished. Command and control duties are carried-out through an assortment of personnel and equipment employed by a commander during planning operations while directing and coordinating operations in the accomplishment of the assigned mission. Blue Force Tracking devices can also serve to improve command and control by enhancing communication accuracy between a commander and his forces in order to accomplish the mission more effectively and timely. This task can be accomplished in several ways. Blue Force Tracking devices can be used to send and receive text messages between commanders and troops very similar to the method in which modern smart cellular phones conduct this type of communication. In a similar fashion, imagery files can also be sent using said handheld devices. Blue Force Tracking systems can aid the warfighter by enhancing the command and control element (Builder, Bankes, & Nordin, 2006).

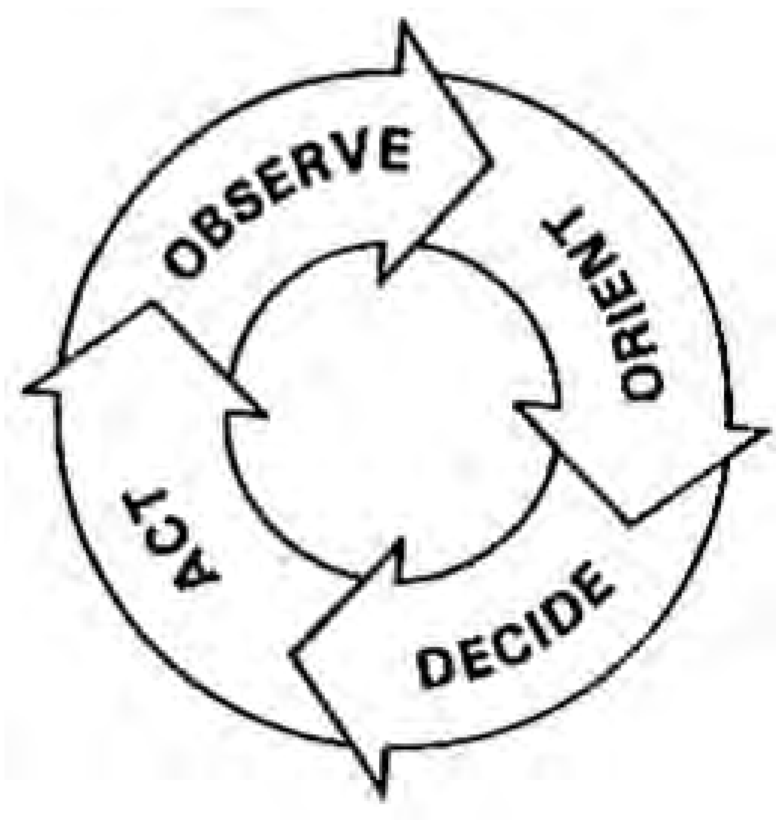

Figure 2. Command and Control Process: OODA Loop (From [Krulak, 1996])

c. Effects on Friendly Fire

In a combat theater, competent Blue Force Tracking systems can be used to alleviate issues related to friendly fire. Similarly, two elementary questions, which are always in a warfighter's mind, "Where am I?" and "Where are my friends?" can now be answered using BFT systems (Jane's Information Group, 2008). Friendly fire is unintentional firing towards one's own friendly forces while attempting to engage enemy forces, particularly where this action results in injury or death. Friendly fire is often regarded as an inevitable result of combat. Attempts to reduce this effect by military leaders generally come down to identifying the causes of friendly fire and overcoming repetition of the incident through training, tactics, and technology.

The primary cause of friendly fire is commonly recognized as the “fog of war,” a phrase coined by the Prussian military analyst, Carl von Clausewitz. This phrase attributes friendly fire incidents to the inherent confusion, which arises out of warfare. Fog of war incidents fall roughly into two classes known as errors of position and errors of identification (Clausewitz, 1968). Error of position occurs as a result of fire originally targeted toward enemy forces, which accidentally ends up hitting one’s own forces instead. These particular incidents are often worsened by the close proximity of opposing forces. As the accuracy of weapons improves over time, this class of incident becomes increasingly less common. Error of identification occurs as a result of friendly troops mistakenly attacking a force that is believed to be the enemy. This type of accident most likely occurs as a result of highly mobile battles and battles involving a multination coalition of forces (Pike, 2011).

A number of situations can lead to or elevate the risk of friendly fire. Common factors include poor terrain and reduced visibility. Battles occurring over unfamiliar terrain can disorient the warfighter more easily than those on familiar ground. The specific bearing from which enemy fire originates may not be easily identifiable. Confusion is often exacerbated by poor weather conditions and stress associated with combat. Battle units require an accurate means of navigation and fire discipline to reduce the risk of friendly fire. In situations where risk is elevated, commanders should ensure their units are properly apprised of the locations of Blue forces. These commanders should issue clear and concise orders without ambiguity. Blue Force Tracking systems can serve as shields to friendly forces resulting in fewer incidents of Blue on Blue engagements and deaths (Pike, 2011).

3. Limitations of Legacy Blue Force Tracking Systems

The Blue Force Tracking network is a satellite-based system and is therefore subject to the limitations of space-based communications systems. Many of the system’s limitations occur as a result of the properties related to space. Some of these limitations include a susceptibility to dead space, blackouts, and solar interference. As a result, current locations are not always updated and messaging functions are disrupted when

BFT signals are blocked from satellite receivers. The blockage can be attributed to rising terrain, satellite position, or both. Shortening the frequency of updates helps alleviate this disadvantage. Consequently, the system presents less timely information, resulting in the lack of a real-time image. Thus, users must maintain a backup tracking system, usually a map and graphics, in the tactical operations center and in the field (Watanabe, 2010).

a. Lack of Real-Time Image

An automatically-updating system, which continuously illustrates the precise location of all friendly forces, can possibly remove any question of accuracy from the user's perspective. Positional data can be automatically filtered and summarized by unit and sub-unit. The reason for this is that when the data moves through the chain of command, the information can be presented at a level appropriate to the viewer or expanded if necessary. As data in the same timeframe becomes available, users are working at a level known as the Common Operating Picture, or COP, and misinterpretations should be minimized (Jane's Information Group, 2008).

In this instance, when communications are interrupted, data can no longer be updated. The updating interval, or the refresh rate, is the anticipated interruption within the system. Most data tracking systems rely on either a time or a distance-moved trigger. This means that positional information is transmitted at either specific time intervals or when the transmitting entity has moved a certain distance. The parameters of these triggers can be altered as the situation dictates. The latency of the system is the unplanned delay or the delay caused by the time it takes to transmit, manipulate and retransmit the data. This period can last up to five minutes in legacy systems. Therefore, legacy blue-force tracking systems do not provide a real-time image of the battlefield as a result of the system's latency (Jane's Information Group, 2008).

b. Terrain Masking

A system that relies solely on terrestrial-based radio frequency communications is affected by fundamental range limitations caused by line-of-sight and interference caused by terrain masking. Such a system makes considerable progress towards de-conflicting forces in theater. However, a fail-safe combat identification method does not yet exist. Additionally, the warfighter's reliance on a Global Positioning System-based capability can be a disadvantage in an urban setting, where the system is less effective, particularly at the level of the individual soldier inside a building (Jane's Information Group, 2008).

c. Security

Legacy systems were designed and built with relatively low security requirements with regard to transmission. Early generation systems lacked link encryption and traffic load masking, and were susceptible to signal jamming. Link encryption is an approach to communications security that encrypts and decrypts all traffic at each end of a communications line. Traffic load is the total information moved over a single transmission channel between two points that are switching centers or nodes during a specified time interval. Signal jamming is the intentional broadcast of radio frequency signals that upsets communication by decreasing the signal-to-noise ratio, or SNR (Gaur, 2010).

B. TECHNICAL SIDE OF BLUE FORCE TRACKING

Blue Force Tracking systems are based on reliable and accurate two-way communications between satellites and satellite terminals. Blue Force Tracking systems consist of a variety of components ranging from handheld tracking devices, ground control stations, computers, satellite antennas, and mapping software to a complex space element involving sophisticated satellites located in various orbital regimes. In order to understand how these communications are enabled, a foundation of the components should be established (Imagery-Intelligence, 2010).

1. Open Systems Interconnection Model

When researching improvements into the realm of satellite communications and tracking, a familiarity and baseline comprehension of the communication systems network architecture is essential. The Open Systems Interconnection model, or OSI model, is a method separating the communications system into its essential parts known as logical layers. Officially, seven consecutive logical layers exist in the model and each layer is related to adjacent layers above and below. An overview of the seven layers within the OSI model is provided in Table 1.

OSI Model			
	Data unit	**Layer**	**Function**
Host layers	Data	7. Application	Network process to application
		6. Presentation	Data representation, encryption and decryption, convert machine dependent data to machine independent data
		5. Session	Interhost communication
	Segments	4. Transport	End-to-end connections and reliability, flow control
Media layers	Packet/Datagram	3. Network	Path determination and logical addressing
	Frame	2. Data Link	Physical addressing
	Bit	1. Physical	Media, signal and binary transmission

Table 1. OSI Model

Layer 1 is known as the Physical Layer. The physical layer conveys the bit stream between the electrical and mechanical specifications for communication devices. This layer defines the relationship between a device and a transmission medium using electrical impulse, light, or radio signal. The physical layer has three major functions.

The first function is to establish and terminate a connection to a communications medium. The next function has to do with the organization of simultaneous contention and flow control between multiple users where resources between the users are shared. The third function has to do with frequency modulation between the user's digital data and the transmitted corresponding signals ("OSI Model," 2010).

Layer 2 is known as the Data Link Layer, in which data packets are encoded and decoded into bits. The data link layer provides the functional medium for data transfer between two host entities on the same network. This layer also has the ability to detect and correct errors that may occur in the Physical Layer, while monitoring flow control and frame synchronization ("OSI Model," 2010).

Layer 3 is known as the Network Layer, which provides switching and routing technologies via a medium for transferring data sequences that vary in length. The node to node transfer occurs from one source host on a particular network to a destination host from an entirely different network. Routing and forwarding are functions of this layer. Secondary functions include addressing, internetworking, error handling, congestion control, and packet sequencing ("OSI Model," 2010).

Layer 4 is known as the Transport Layer. This layer provides seamless integration and reliable transfer of information from multiple end users or hosts. This layer controls the reliability of a given link through flow control, segmentation or desegmentation, and error recovery. The Transport Layer can monitor the progress and status of segment transmissions and has the ability to retransmit failed broadcast ("OSI Model," 2010).

Layer 5 is known as the Session Layer. This layer establishes, coordinates, and terminates the connections between the local and remote computer systems. This layer is responsible for a close of dialogue, session checkpoint, and session recovery ("OSI Model," 2010).

Layer 6 is the Presentation Layer, which is also called the syntax layer. This layer establishes context between Application Layer entities, while providing independence from data representation by translating between application and network formats ("OSI Model," 2010).

Layer 7 is called the Application Layer, which is the supporting OSI layer closest to the user in order to support end-user processes. Essentially, the OSI application layer and the user interact directly with the software application. This layer provides application services for file transfers, e-mail, and various network software services. This layer includes tiered application architectures ("OSI Model," 2010).

2. Ground-Based Aspect of Blue Force Tracking Systems

Blue Force Tracking systems typically include a computer, which is generally used to display location and timing information. The system also uses a satellite terminal and satellite antenna, which is used to transmit location derived from a Global Positioning System receiver in order to determine its own position. Additionally, the system requires command-and-control software in order to send and receive communications. Location information is provided via mapping software, as illustrated in Figure 3, usually in the form of a Geographic Information System, or GIS, which plots the Blue Force Tracking data on a map. The system computes the information and displays the location of the host vehicle on the computer's terrain-map display along with the locations of other platforms. Friendly forces appear as the color blue and enemy forces appear as the color red in their respective locations (Imagery-Intelligence, 2010).

Figure 3. BFT Computer Display (From [Bordetsky, 2010])

a. Handheld Devices

Details of the handheld devices used for Blue Force tracking can vary slightly depending on the manufacturer and the customer's specific requirements for the device itself. In this regard, the handheld device is capable of a variety of features. The device can be as small as a modern smart phone, while weighing under 5 ounces. The multicolor touch screen display is usually 2.5 inches with 320 by 240 pixel resolution. Some handheld devices can have a 2.0-megapixel autofocus camera with digital zoom with camcorder. Some devices are equipped with a notification light for messaging and missed calls, using a charging Light-emitting diode, or LED, indicator and an ambient light sensor. Older systems can be much larger in physical size with a much more noticeable satellite antenna (TerreStar Networks, 2011).

(1) Voice Communication. Voice communication occurs through an audio speaker and microphone. The device can also be set up to communicate through a stereo-wired headset. Some devices have Bluetooth capability very similar to modern cell phones (TerreStar Networks, 2011).

(2) Text Messaging. Text messaging can be accomplished via the user interface through Windows-based software through a keyboard with 30-40 buttons, five-way navigation key, two customizable application keys, two soft keys, Windows Mobile Start Button, OK key, send key, and an end/power key (TerreStar Networks, 2011).

b. Tracking Capabilities and Accuracy

Positional tracking is accomplished through the use of Global Positioning System satellites, as illustrated in Figure 4. “Each of the deployed terminals uses a GPS receiver to determine its position and an L-band transceiver to send data back to the system via satellite” (Brinton, 2010). Tracking information is shown to the user via a display or a computer monitor. A minimum of three satellites is required to determine position on a two dimensional surface. However, elevation information for personnel on mountainous terrain and altitude data for aircraft require a minimum of four satellites. Accuracy increases with the number of satellites in line-of-sight contact with the receiver.

Figure 4. GPS Satellite (From [Space Today Online, 2006])

3. Space-Based Aspect of Blue Force Tracking Systems

Blue force tracking systems are made available through satellites operating in Space. These satellites may have a number of different orbital regimes. Additionally, satellite constellations are comprised of a various number of satellites each performing a dedicated task in conjunction with one another.

a. Orbital Regimes

Earth orbiting space vehicles may exist in four different regimes, as illustrated in Figure 5. Low Earth Orbit, or LEO, is the regime closest to the Earth ranging from surface to an altitude of 2,000 kilometers. Geostationary Earth Orbit, or GEO, is the farthest circular orbital distance from the Earth and begins at a distance of 23,200 kilometers. Medium Earth Orbit, or MEO, exists in the region between LEO and GEO. The fourth basic regime is called Highly Elliptical Orbit, or HEO. This orbit is an elliptical orbit with perigee occurring at low altitude and apogee occurring over 35,700 kilometers above the Earth's surface (Ancillary Description Writer's Guide, 2010).

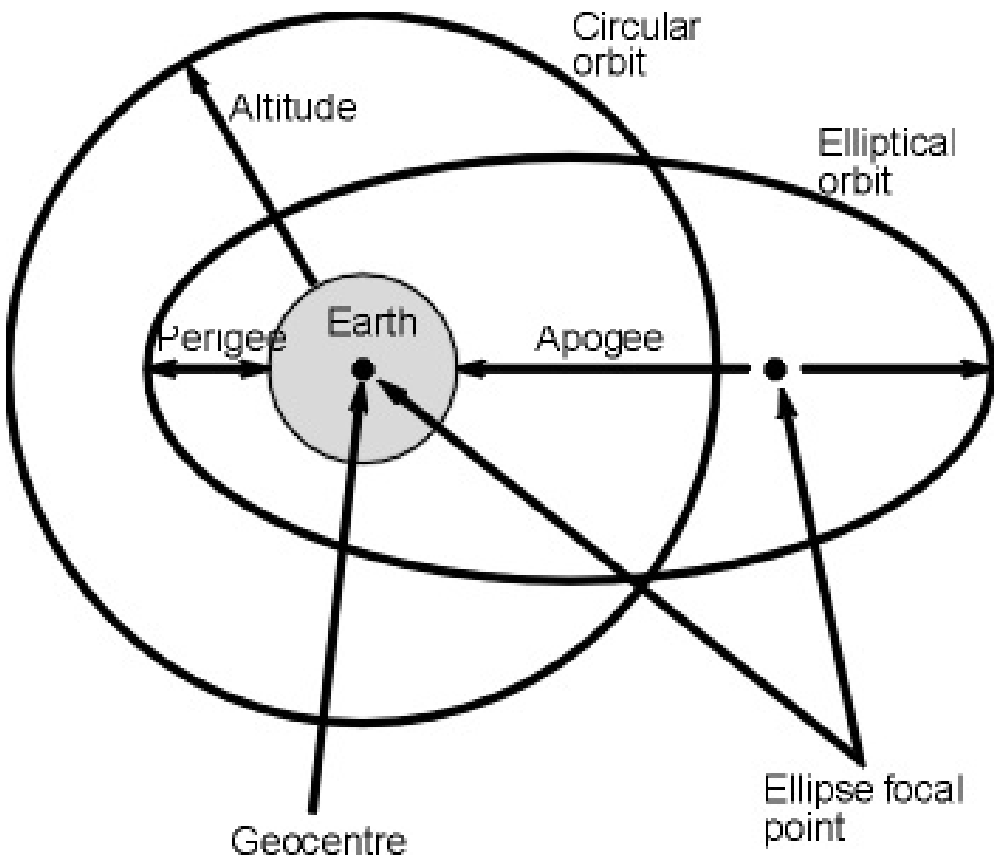

Figure 5. Orbital regimes (From [Johnson, n.d.])

b. Satellite Constellations

The Global Positioning System is comprised of a minimum of 24 satellites in Medium Earth Orbit, as illustrated in Figure 6. Four satellites occupy each of six orbital planes. The inclination of the six planes is approximately 55 degrees. The six planes are evenly separated by 60 degrees. Space-based Blue Force Tracking systems also require a minimum of one satellite in geosynchronous orbit. This spacecraft must remain within line-of-site contact with the user device at all times in order for the system to function.

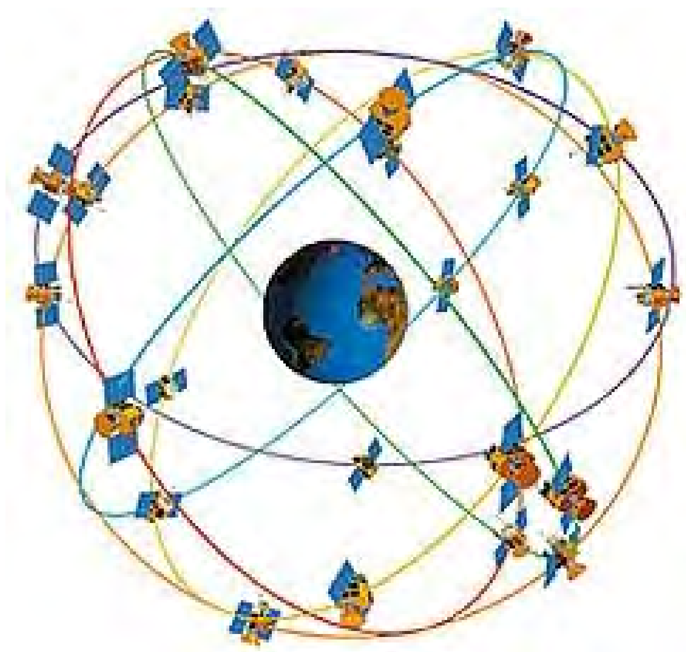

Figure 6. GPS Satellite Constellation (From [Tech-Ex, 2011])

C. PROVIDERS OF BLUE FORCE TRACKING SYSTEMS

Leading providers of current Blue Force tracking systems include such contractors as TerreStar, ViaSat, and General Dynamics.

1. TerreStar

The TerreStar Corporation is at the forefront of supplying a dependable and secure satellite terrestrial mobile broadband network currently with the use of one satellite over North America in GEO. This network presents voice and data plans established to assist in solving the vital communication and business continuity obstacles "faced by government, emergency responders, enterprise businesses and rural communities" (TerreStar Networks, 2011). TerreStar presents next-generation portable communication devices via a network of partners and service providers to clients who require anywhere-coverage (TerreStar Networks, 2011).

Figure 7. Terrestar-1 (From [Terrestar, 2011])

2. ViaSat

As a next-generation upgrade to the United States Army and Marine Corps Blue Force Tracking network, ViaSat enhances real-time situational awareness and provides improved networking capabilities to the warfighter-community with BFT-2. ViaSat's next-generation Blue Force Tracking transceivers possess spectacular upgrades in "situational awareness through faster Position Location Information (PLI) refresh rates, and greater information throughput features" (ViaSat, 2011). This BFT-2 system brings better network efficiency and "reduces the Department of Defense's total operational expenditure for the specified capability" (ViaSat, 2011).

Figure 8. ViaSat-1 (From [ViaSat, 2011])

3. General Dynamics

General Dynamics generates and incorporates Blue Force Tracking with heightened situational awareness potential into goods and systems, which can identify and track Blue forces in an effort to save lives. These new systems form a "tiered architecture using ground, airborne, over-the-horizon (OTH) relay, and national asset segments to prevent fratricide, track valuable military assets, provide emergency communication, exfiltrate data from sensor systems, and allow search and rescue forces to quickly locate, identify, and communicate with at-risk personnel" (General Dynamics, 2011). As one of the leading developers of Blue Force Tracking systems, this corporation uses the most recent developments in advanced signal processing and waveform technologies with regard to producing Blue Force Tracking solutions (General Dynamics, 2011).

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III. CAPABILITIES OF THE TERRESTAR CONSTELLATION

A. TERRESTAR-1 OVERVIEW

TerreStar-1 was, as illustrated in Figure 10, launched on July 1, 2009, and was constructed by Space Systems/Loral. The satellite's antenna is nearly 60 feet across and supports 500 dynamically configurable spot beams. The spot beam technology, coupled with Ground Based Beam Forming, or GBBF, allows TerreStar to allocate power and spectrum to situation-specific incidents ensuring capacity when and where it is needed. TerreStar's network operates in two 10-Mhz blocks of contiguous mobile satellite service, or MSS, spectrum in the 2 GHz band throughout the United States and Canada (TerreStar Networks, 2011).

Figure 9. Terrestar-1 2009 Launch (From [Terrestar, 2011])

TerreStar-1 is, as illustrated in Figure 11, a geosynchronous satellite covering North America and supports the delivery of advanced all Internet Protocol, or IP-based, mobile data and voice services (TerreStar Networks, 2011).

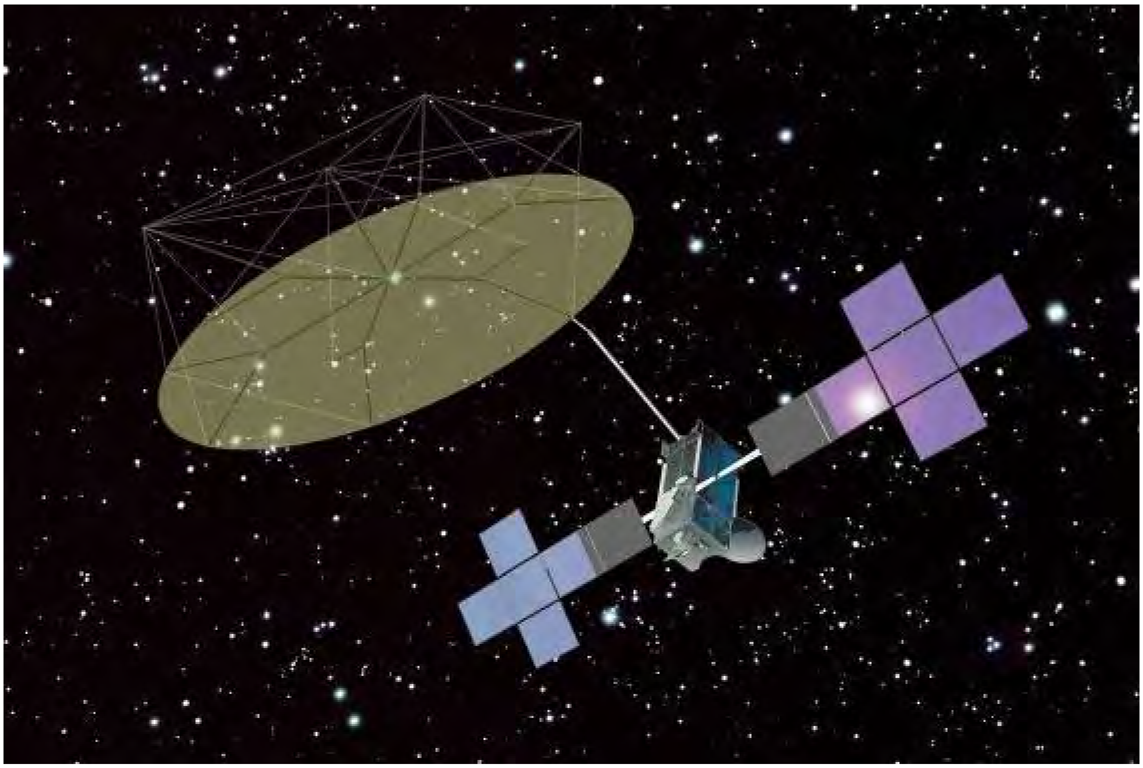

Figure 10. Terrestar-1 in Orbit (From [Terrestar, 2011])

B. TERRESTAR-1 SPECIFICATIONS

TerreStar-1 is in an orbital slot at 111 degrees west. The satellite has an 18-meter two Gigahertz S-Band reflector. The satellite is approximately five stories tall and weighs 15,220 pounds. The system provides coverage for the Continental United States, Canada, Puerto Rico, U.S. Virgin Islands, Hawaii, and Alaska (TerreStar Networks, 2011).

C. TERRESTAR-1 ADVANTAGES

1. Commercial

TerreStar offers several advantages to the commercial market. Currently, TerreStar is the sole provider of satellite and cellular communications on a Smartphone device. TerreStar's system serves to enable "always available" mobile communications. The TerreStar GENUS provides cellular phone communications through AT&T's network and offers backup satellite communications through the TerreStar network. This service provides redundant communications in remote areas of the United States and also when wireless networks are unavailable. TerreStar's Smartphone features such as text, e-mail, contacts and calendar are made available in satellite and cellular mode (TerreStar Networks, 2011).

2. Government–Nonmilitary

TerreStar offers several advantages to the government sector. In a post-September 11th, Hurricane Katrina, and Haiti earthquake era, fewer necessities are as crucial as robust and "uninterrupted communications for the nation's homeland defense, homeland security, and public safety first-responders" (TerreStar Networks, 2011). The TerreStar network enables access to wireless communication coverage in remote areas when cellular networks are not available. New Blue Force Tracking devices can serve to provide command and control via communications to emergency responders in the beginning hours of a disaster (TerreStar Networks, 2011).

3. Government–Military

TerreStar also offers several advantages to the military sector. Blue and Red Force tracking combined with increased communication abilities spread from the battlefield commander to individual soldiers, tanks, aircraft, and ships. This concept drastically changes current command and control structures by increasing communications to all warfighters.

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IV. SURVEILLANCE TECHNIQUES THAT ENABLE TRACKING SMALL VEHICLES AND BOATS

A. VISUAL METHODS AND SHORTCOMINGS

Now that TerreStar has been discussed in terms of technical specifications and capabilities, it is time to take a look at why TerreStar is important in the field of tagging and tracking small objects ranging from cars to boats to briefcases. There are several ways to conduct surveillance when trying to track objects and among these methods is visual surveillance, which can be conducted either on the ground or from the air.

1. Ground Surveillance

Traditional, visual tracking techniques generally require the tracked object to be visually observed at all times in order to ensure chain of custody. This concept can be an expensive and labor intensive task requiring the use of personnel, vehicles, aircraft, sensors for both night and day or some combination of these assets. Limitations are present with each of these scenarios. Trying to track an object from the ground is typically very difficult. The person conducting the tracking can easily lose sight of the target if the surveillance is being conducted in heavily trafficked areas. Additionally, when the surveillance is being conducted on foot if the target enters a vehicle it can quickly exit the area being covered from the ground. Vehicles can also easily be lost in heavy city traffic when the tracking team gets stuck in traffic and is unable to follow. As soon as the chain of custody of the object being tracked is lost, it can be difficult to re-establish the chain of custody with any degree of confidence that a switch has not taken place.

2. Aerial Surveillance

Typically, if the subject being tracked enters a building, the chain of custody is immediately lost until a ground asset can follow into the building, which may not be possible. In remote areas without other activity occurring, the units conducting surveillance of vehicles, aircraft, or personnel can stand out to the subject being tracked. Aerial surveillance can also be costly with operating cost for aircraft adding up quickly. Aircraft also have a limited time on station typically being on the order of a few hours.

B. ELECTRONIC METHODS

In addition to visual methods to tagging and tracking there are also electronic methods, which are the focus of this thesis. There are generally two types of electronic tagging, active and passive. The Radio Frequency ID tag is the most typical in use today and is widely used by the United States military. The requirement for the use of RFID tags by the military is established in the Defense Federal Acquisition Regulations (DFARS clause 252.211-7600).

An active tag has its own power source and transmits anytime it detects it is being interrogated. A passive tag has no power source and requires an externally generated electromagnetic field. The benefits of either types of tagging vary slightly. An active tag generally has much greater range since it has its own power source, but a passive tag is harder to detect. Other types of tags such as GPS, Wi-Fi, and Bluetooth are used as well. These tagging methods are summarized in Table 2 from Clarinox Technologies (Clarinox Technologies 2009).

	RFID-passive	RFID-active	Bluetooth	WiFi	GPS
Power Usage	None	Low to Medium	Medium	High	Medium
Data rate	Low	Low to Medium	Medium to High	High	Not Applicable
Coverage	Low	Medium	High	High	Very High (outdoor)
HW costs	Tags-low Readers-med to high	Medium	Medium	High	High

Table 2. Real-Time Locating System Comparison (From Clarinox Technologies 2009).

Each of the types of tags listed in the table has advantages and disadvantages. Table 1 highlights some of the most common types but does not address emerging technologies in the real-time locating field, such as TerreStar which can play a vital role. Also, there can be an argument about whether or not Bluetooth and Wi-Fi are actually tags or if they just relay data provided by another source such as a GPS tag.

a. Tag Interrogation

Bluetooth, Wi-Fi and TerreStar are all considered active tags since they all have a power supply. This means that they are constantly transmitting a signal that would be detectable to someone trying to determine if they have been tagged. This makes tracking a tag covertly more difficult since anyone searching for the tag is able to interrogate it. Bluetooth and Wi-Fi are typically always emitting a signal looking to make a connection with another Wi-Fi or Bluetooth enabled device therefore making their signal easier to detect since they actively want to be detected and transmit data. The Global Positioning System is looking to receive the GPS signal, a relatively weak signal, which might make this type of tag harder to detect. However, if the GPS tag is only receiving the signal, it may know where it is, but it still needs some way to transmit its location. This action requires a separate transmitter and this is where the argument enters for whether or not Wi-Fi and Bluetooth are actually tags since they provide a method of transmitting a GPS signal, but alone would not be able to determine their position and relay it. Therefore, while GPS may provide an accurate location, the transmitting device still needs to be incorporated into another network, of which TerreStar is one possible option.

b. Ability to Inject Data into the Tracking Network

A significant advantage of TerreStar is the higher capacity data rate that can be transmitted over the network compared with some other methods, up to 400kbps. Bluetooth and Wi-Fi both offer a high data rate, but require a connection to a network. In general Bluetooth and Wi-Fi networks are not widespread when compared to a cell phone network or a satellite in geosynchronous orbit. Although today Wi-Fi networks can be found everywhere from your home to the local Starbucks they have a short range, on the order of tens of meters, and as a result only cover a small area compared to a cell network or satellite in GEO which can cover hundreds of square miles. TerreStar can transmit data over either its cellular or satellite connection enabling it to inject data over the network in a timely manner. Bluetooth and Wi-Fi may not provide real-time tracking since they can only update their location or transmit data when they make a connection with the network, which in more sparsely populated areas may not be frequent enough to establish a workable track. TerreStar, with its use of cellular and satellite, can continuously update its location providing for a more accurate real-time tracking capability.

c. Tags That are Evaluated

For purposes of this thesis, different types of electronic tags will be evaluated. The primary types of tags that will be examined are cellular based tags and satellite based tags. All the tags that will be studied receive the U.S. GPS signal. The primary focus is how the tags relay that position back to a situational awareness client either via cellular or satellite transmission. For this reason RFID tags will not be studied since they require a chokepoint to download data, and do not use a GPS signal since their position is known when they pass through the chokepoint. Similarly Blue Tooth and WiFi type tags will not be studied because similar to cellular and satellite they are backhaul methods for relaying data. Blue Tooth tags also need to be in close proximity to another Blue Tooth enabled device in order to relay their data and WiFi tags need an already established network in order to make a connection to relay their data. WiFi networks, for now at least are not widespread and not one large network but several separate small networks run by different network companies, unlike cellular networks or satellite networks, which generally only have a few major carriers.

V. CYBER DISTORTION EFFECTS ON TAGGING AND TRACKING

A. DEFINITION OF CYBER DISTORTION

There are several problems that can result in a location error. This error can range from a few centimeters to tens of meters. These errors can result from problems in the mathematical algorithms used to compute location or system noise, which disrupts one or more of the signals used in computing location. Another source of error is latency of the signal as it works its way through the system. The device must first compute its location, then transmit that signal to the SA view and if the SA view is being viewed from a location other than the operations center at NPS the signal must be relayed again over the internet. This error is a primary area of study by the Tactical Network Testbed (TNT) team. The TNT is a consortium of U.S. Special Operations Command and Naval Postgraduate School researchers who conduct quarterly testing of different network topologies and technologies. One of the goals of the TNT team is to better connect the warfighter in the field with resources and technology not currently available that can give them better situational awareness. A term used by the Tactical Network Testbed team for this type of location error is "cyber distortion" and the team identified it as follows:

> A major problem in tracking and interdicting targets on foot appeared to be the significant discrepancy between the target's location on the Situational Awareness view map and its actual physical location. The experimentation group on site identified that this distortion could be compensated for, ad hoc by using a number of short-haul tag detection manned or unmanned nodes. A focus of the next experiment should be to identify scale and triangulation support techniques for operators with short-haul detectors, augmented by the distorted SA feedback from the Tactical Operations Center. (Bordetsky, November 2010)

Essentially, the researchers in the experiment increased the size of the network in an effort to get more data points for triangulation of the signal. This may not be sufficient to overcome the distortion in the SA view due to the fact that there are multiple possible reasons for the distortion.

B. SOURCES OF DISTORTION

1. Global Positioning System

The most accurate of all the different types of tags is the U.S. built Global Positioning System. As noted in the Table 1, GPS offers high coverage and accuracy. The GPS constellation of satellites offers worldwide coverage with high accuracy as low as six meters in ideal conditions (Department of Defense, 2008). However, some disadvantages also exist. GPS receivers generally require a clear line-of-sight to three or more satellites in order to establish an accurate location. This means that when a target enters a building or tunnel, the signal could be lost, similar to losing visual surveillance. Other disadvantages of the GPS constellation include its susceptibility to jamming coupled with the fact that it is a receive-only system, so other data cannot be injected into the network. The inherent accuracy limitation of the GPS system and its susceptibility to jamming both represent possible sources of distortion. As previously stated though, a GPS tag still needs a method for backhauling the data.

2. Global System for Mobile Communications (GSM)

Typically, a cellular phone can be located to within several meters by triangulation of the cell signal using cell towers. Several years ago, experiments in England recorded an area of uncertainty ranging from a few hundred meters to several kilometers (Mathiesen, 2004). The obvious limitation to the cellular tagging and tracking method is that it requires cell towers to be present and in sufficient density to triangulate the signal. Therefore, this method would be more accurate in urban terrain but less effective in more sparsely populated areas. Many cell phone developers have started to incorporate built-in GPS receivers to improve the geolocation accuracy. This improvement essentially makes the phone a GPS tag instead of a cellular tag. Since cell phones have essentially become GPS tags they suffer from the same limitations cited for the GPS tag. The cellular network does, however, provide a method of transmitting the GPS signal back to a location where it can be tracked. Tracking this type of tag though will be difficult in areas with weak cell reception. The delay in the cellular network, though, should be minimal, at less than 1 second, providing near real-time updating of the location with the accuracy of GPS.

3. TerreStar

One focus of research into the application of TerreStar as a tagging device is the error ellipse for tracking a TerreStar receiver. A TerreStar device receives the GPS signal to locate itself and then transmits that position over either its cellular or satellite network. If one signal is lost, the device can easily switch to the other signal. This action allows tracking in sparsely populated areas where cellular service is not available. Additionally, in high terrain where a cellular signal might be blocked, a satellite in geosynchronous orbit offers advantages over other satellite communication systems such as Iridium. Iridium can quickly hand-off calls from one satellite to the next, but could potentially hand-off the call to a satellite that is obstructed by terrain and thereby lose signal reception. In a 2002 study conducted by Frost & Sullivan for an 8 minute 30 second call Iridium dropped 18.4% of calls and GlobalStar 2.6%. When the study looked at urban and rural areas the call drop rate increased significantly to 70.4% and 40.7% for Iridium and 64.5% and 37.0% for GlobalStar. If trying to track a target using this technology this would be a large percentage of targets where tracking ability was lost using a purely satellite based solution. (Frost & Sullivan, 2002) TerreStar offers the benefit in challenging terrain of switching to the cellular network if available to continue to track a target. Another benefit of the combined cellular/satellite system is the increase in augmented GPS. Many cell towers are now being accurately surveyed using GPS and equipped with devices that transmit that accurate location to cell phones within range of the tower. This type of device integrated into cell towers allows for the TerreStar device to receive a signal over the cellular network which directs the TerreStar device to the satellites it should use to receive the GPS signal. This reduces the time it takes to acquire a GPS satellite lock.

C. METHODS FOR MITIGATION

1. Combining Various Sources to Provide Overlapping Coverage to Reduce Overall Error Area

One way that the problem of cyber distortion was solved during the TNT experiments was to add more short-haul tag detectors. If one looks at this in terms of a cell phone, the team basically added more cell phone towers to have more data to locate the tag. The TerreStar network, by way of cellular, satellite, and GPS signals all in one receiver, allows for the use of several different types of signal to help reduce the size of the error ellipse.

2. Increasing Signal Strength of Receiver

Another aspect of the TerreStar network is that it has beam-forming capability, which can increase power to areas where more bandwidth or power is needed. This offers the advantage that it reduces susceptibility to jamming. Through allocation of more power to a single spot beam TerreStar offers the ability to "burn through" any jamming that may be directed at the target. Since the TerreStar satellite uses configurable spot beams, within the entire coverage area of the satellite, only the spot beam footprint containing a jamming device is jammed, as opposed to all 500 individual spot beams within the entire satellite coverage area.

VI. EXPERIMENT I

A. EXPERIMENT BACKGROUND

The first experiment conducted as part of research into the applicability of the TerreStar Satellite to tagging and tracking was conducted in conjunction with the Tactical Network Topology Experiment 11-3 on 11 May 2011 at Camp Roberts, California. Although the TerreStar devices had not yet been acquired three other comparable systems were available for testing. These devices consisted of a BlackBerry messenger, a Blackbird GPS tag, and a Trellisware TW-220 CheetahNet radio. Each of these devices operates in a different manner and in a different spectrum and provides insight into the gaps in coverage of the devices, which TerreStar may be able to address. Before the conduct of the experiment is explained background on the tested devices will be covered.

1. BlackBerry Messenger

The first device that was tested was the BlackBerry Messenger device, shown in Figure 12. This is a standard BlackBerry device that has been programmed to interact with the Situational Awareness Agent developed at the Naval Postgraduate School to link various situational awareness tools to a single display. The device operates over available terrestrial cellular links. The device receives a GPS signal and relays its position to the SA agent at NPS over an available cellular network. The device has a built in feature where it must detect that it has a horizontal accuracy of 30 meters or less or it will not transmit its location. Similar to GPS systems in use by the military the device develops a Figure of Merit to determine how accurate its location is. Using the SA agent at NPS over the internet, the device can be tracked on a visual display anywhere. In the case of this experiment the Tactical Operations Center (TOC) at McMillan Airfield watched the track of the tag. From the TOC the signal was also relayed by a 5.5GHz link to the mobile command post located at the test start point. Figure 13 is an OV-1 of the BlackBerry tag operation for Experiment 1. The device updates its position every few seconds. In practice the average update occurred approximately every 5 seconds.

Figure 11. BlackBerry Tag

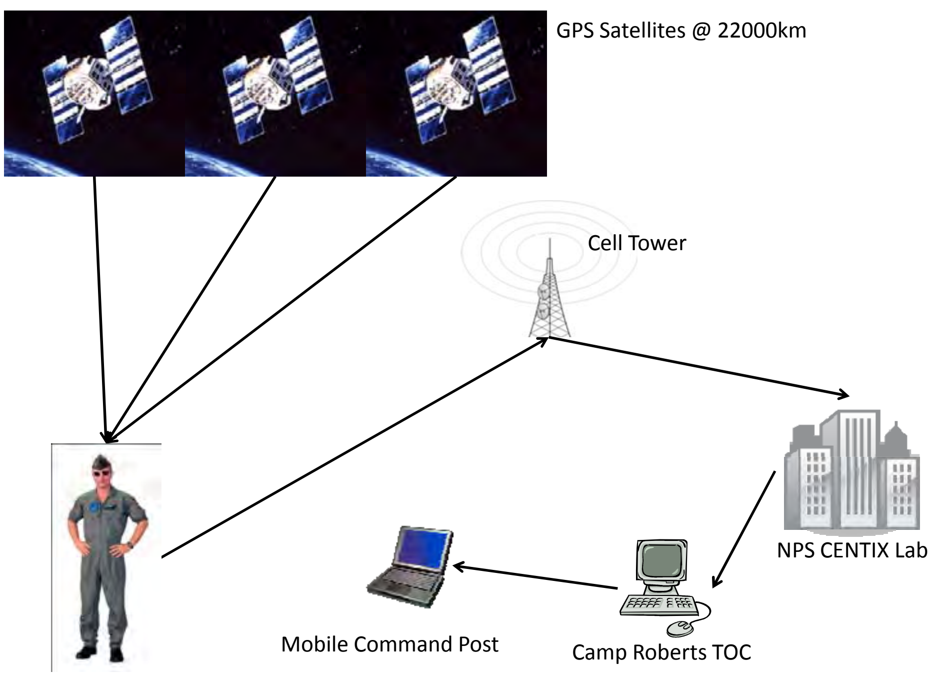

Figure 12. OV-1 Diagram of BlackBerry Tag

2. Blackbird GPS Tag

The second device that was tested was the Blackbird GPS tag developed by Alpine, shown in Figure 14. This device is solely a GPS tag that receives GPS data and then, at a preprogrammed interval, relays that GPS data to the SA agent at Naval Postgraduate School. The shortest interval available is 1 minute. The reason the shortest interval is set at 1 minute is that each data transmission, regardless of amount of data sent, costs $0.10. This is a hardware limitation that the manufacturer chose. This device is a satellite-based device that uses the GlobalStar constellation to relay its data. The GlobalStar constellation is a constellation of 48 satellites located in Low Earth Orbit at 1400km altitude. The system architecture is bent pipe. This means that the signal received on the satellite is relayed without being processsed to a ground station to complete the call/data-transmission over terrestrial links. Once the satellite receives the signal it then relays the signal to the SA agent at NPS; from that point on the tag is displayed and relayed in the same manner as the BlackBerry tag. Figure 15 shows an OV-1 diagram for how the GlobalStar tag operated for Experiment 1.

Figure 13. Blackbird Tag

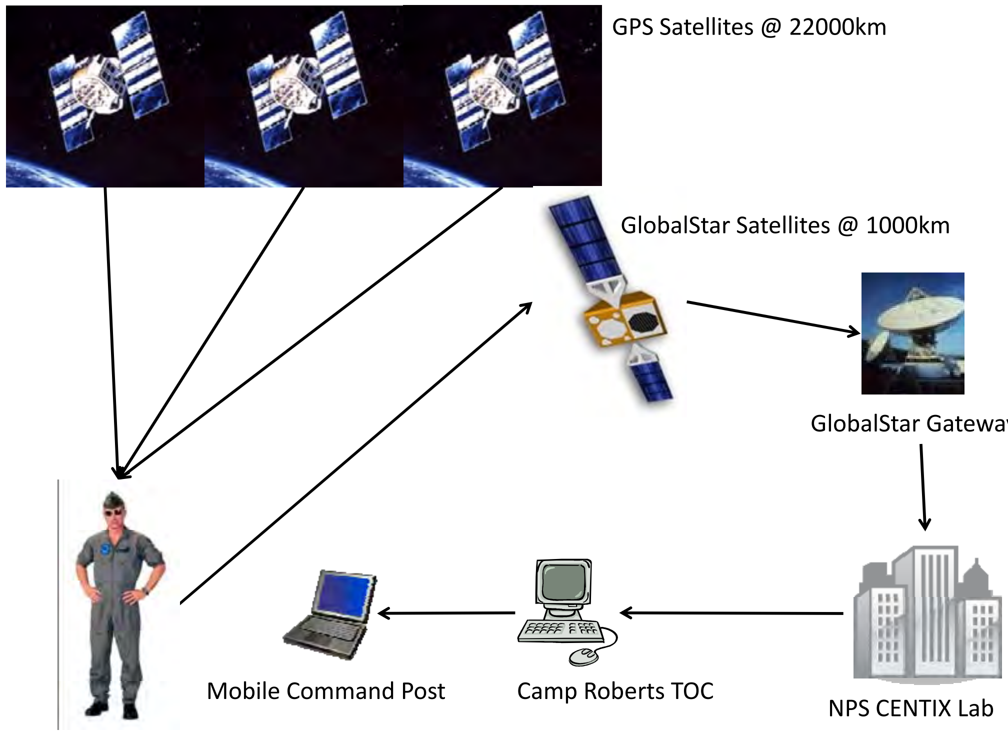

Figure 14. OV-1 Diagram of Blackbird Tag for Experiment 1

3. Trellisware TW-220 CheetahNet Radio

The third device tested was the Trellisware TW-220 radio. These radios, shown in Figure 16, create mobile ad hoc networks. The devices can be used for voice and data transmissions making them extremely useful for tagging and tracking. The primary shortcoming of these radios is that they operate only by line of sight, which makes them of limited use in rough terrain unless the area can be saturated with units. These radios, however, have a much shorter link distance to cover as they are capable of relaying their position directly to the mobile command post as shown in the OV-1 diagram (Figure 17). The data from the radios flows in the reverse direction back to NPS compared to the data from the BlackBerry and Blackbird tags.

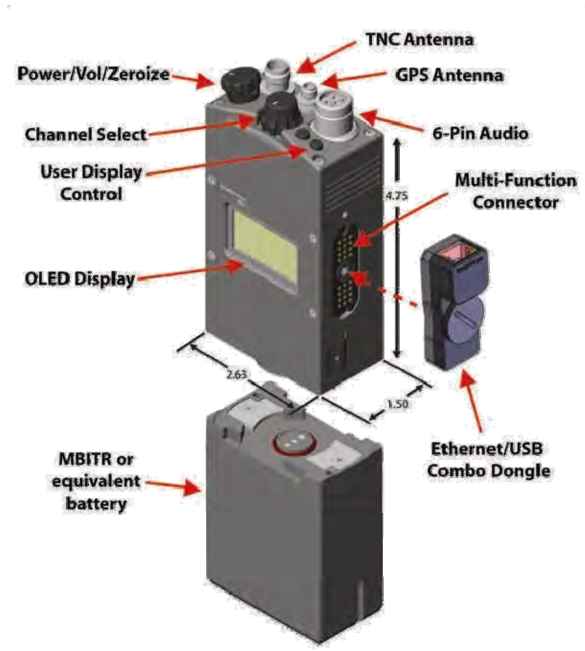

Figure 15. Trellisware TW-220 radio

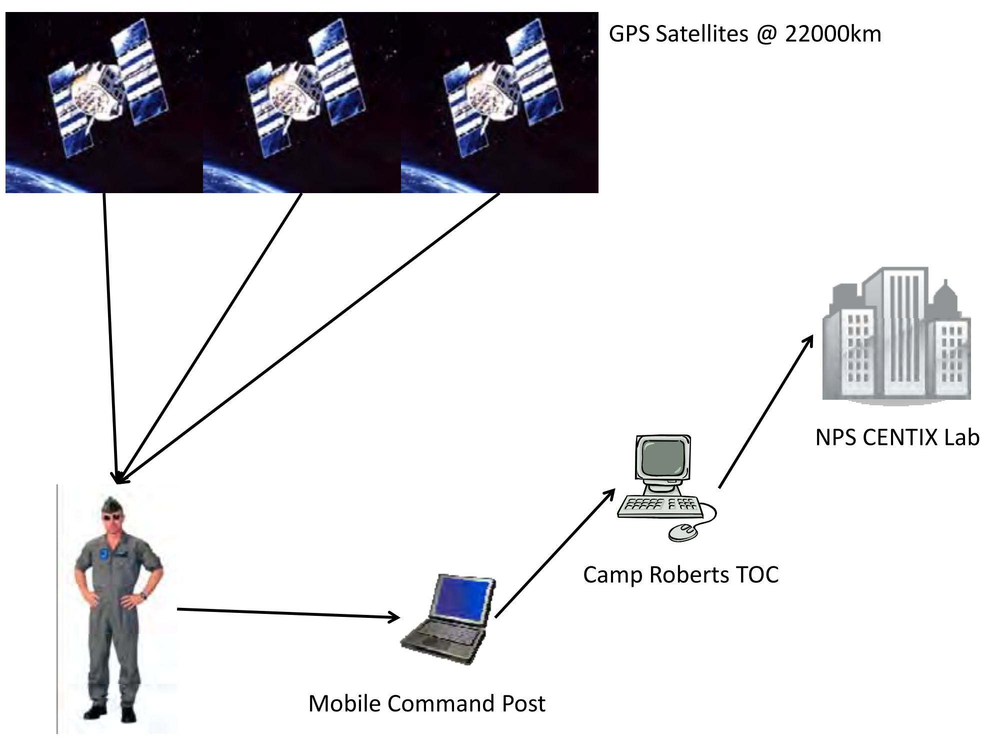

Figure 16. OV-1 Diagram for Trellisware Radio for Experiment 1

B. LOCATION OF TEST AND PARTICIPANTS

As previously stated the test was conducted as part of the Tactical Network Topology Experiment 11-3 on 11 May, 2011 at Camp Roberts, California. On board Camp Roberts the experiment was conducted in the vicinity of McMillan Army Airfield located on the south eastern edge of Camp Roberts as pictured in Figure 18. The terrain in the area of the experiment consisted of tall grass, small hills no more than 150ft high and sporadic tree cover with trees not exceeding 50ft in height. Overviews of the test site in relation to McMillan Air Field can be seen in Figures 18 and 19.

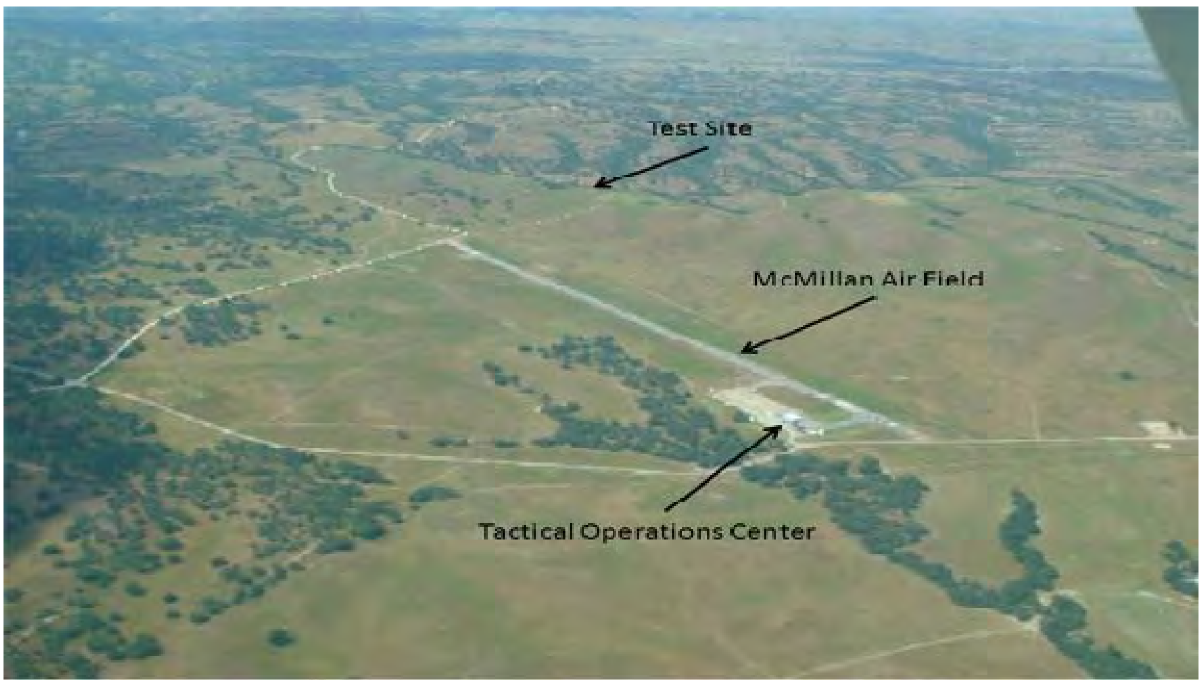

Figure 17. Aerial View of Experiment Location

Figure 18. Aerial View of Test Site

The participants in the experiment consisted of four thesis students from the Naval Postgraduate School working in conjunction with members of the California Department of Forestry and Fire Protection (CDF). Two thesis students performed the tagging and tracking experiment while two other thesis students conducted a separate experiment into the use of the Trellisware radios for forming mobile ad hoc networks. The participants from CDF provided two vehicles that were tagged and tracked for purposes of the experiment.

C. CONDUCT OF EXPERIMENT

The experiment consisted of three separate trials. The three trials were conducted to verify results and in the case of the Trellisware radios to attempt different configurations of vehicles to see if line of sight issues could be overcome. The three trials were conducted between 1100 local time and 1400 local time. The weather for all three trials was the same; sky clear, winds between 10 and 15 knots, and temperatures in the mid-70's Fahrenheit. At the start point of all three trials was a mobile command post equipped with a data-link to the TOC, located at the airfield, and laptops equipped to show the tracks of the various tags employed. The BlackBerry and Blackbird tags relayed their data back to NPS, via either cellular or satellite, and the data was then transmitted to the TOC via Internet links and subsequently over the data-link to the mobile command post. The Trellisware radios, since they are not equipped with a cellular or satellite link and require direct line of sight, relayed their data to the mobile command post first, then the mobile command post relayed their track information to the TOC. Figure 20 shows a topological view of the test area from the USGS 1:24000 Adelaida, California Quadrangle Map using NAD 27 for polyconic projection and NGVD 29 for vertical datum. Four Points are marked on the map; Start/End Point, Point Alpha, Point Bravo, and Point Charlie. Each point is shown with the closest estimate of elevation based on the contour interval, which is 20 feet. For each point an elevation analysis was conducted, as shown in Figures 21, 22, and 23, to help visualize expected line of sight issues with the test start point where the mobile command post was located. This was especially important for determining points where the Trellisware radios could be expected to lose line of sight and where the BlackBerry and Blackbird tags may prove more useful or be able to supplement the Trellisware radios.

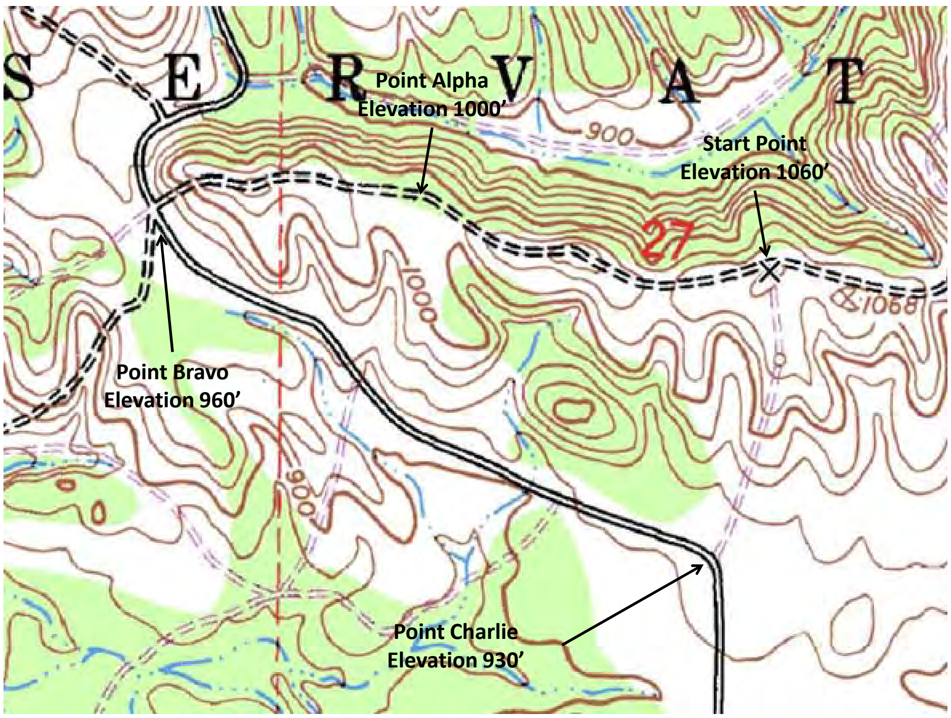

Figure 19. Topographical Map of Test Area

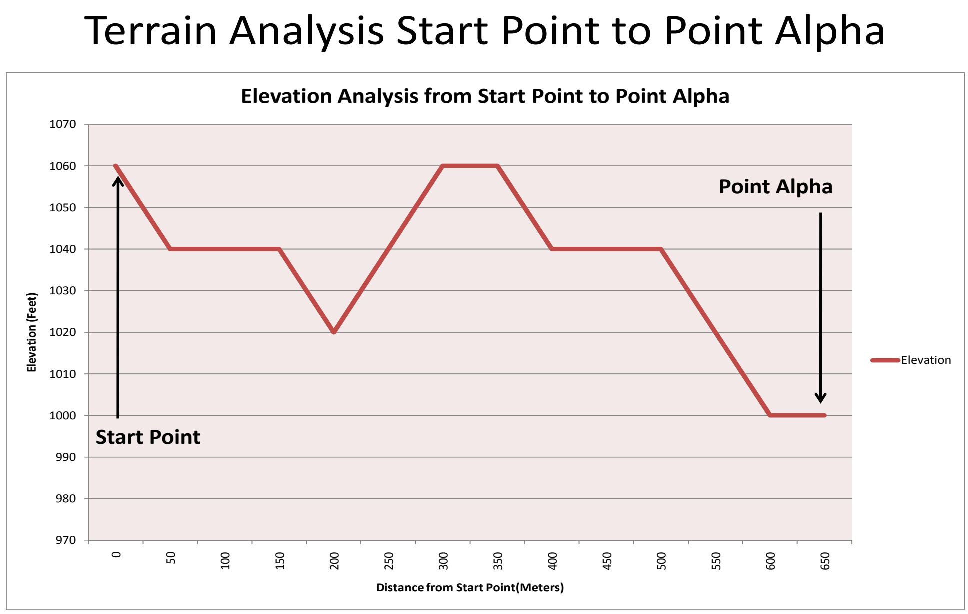

Figure 20. Terrain Analysis 1

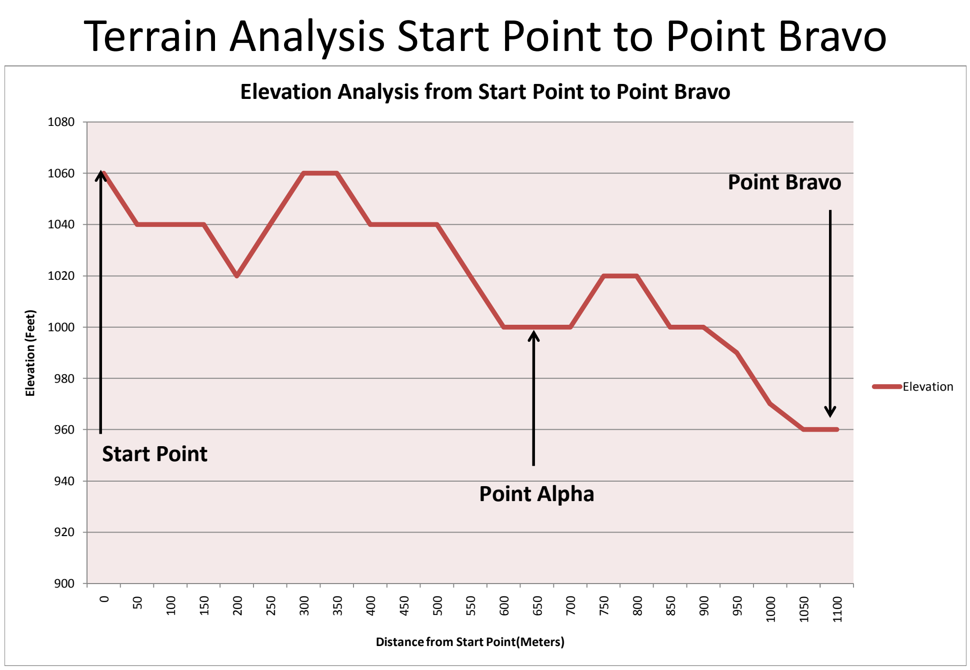

Figure 21. Terrain Analysis 2

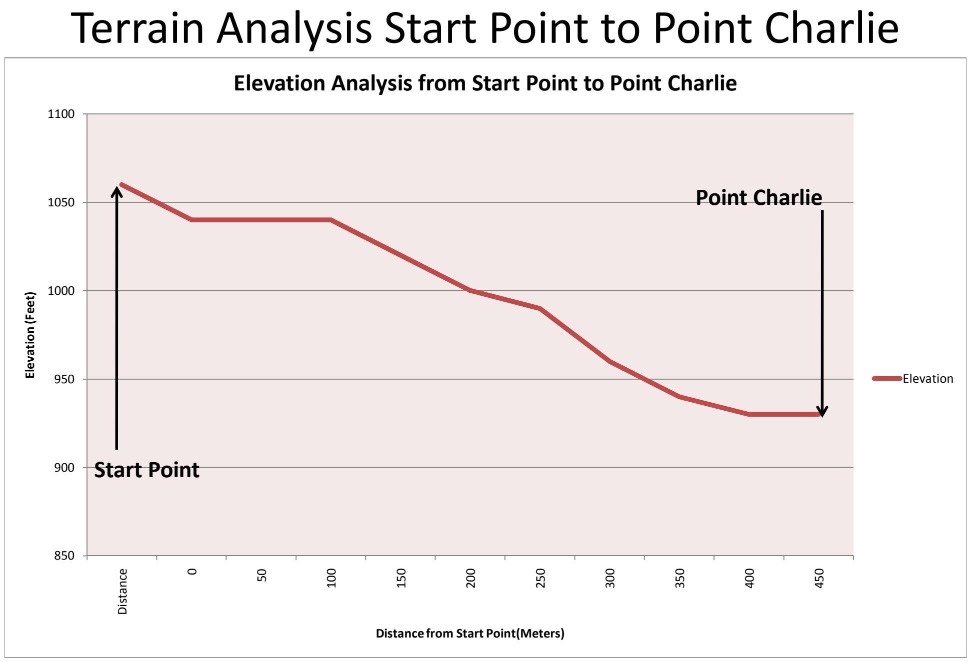

Figure 22. Terrain Analysis 3

1. Trial One

For the first trial, Trellisware radios were placed in both CDF vehicles. The one available Blackbird tag and one available BlackBerry tag were placed in the same vehicle on the dashboard to ensure that nothing in the vehicle would interfere with a clear view of the outside. This is especially important for the Blackbird tag, which needs an unimpeded line of sight to the sky to complete the satellite link. The Blackbird tags were therefore placed on the dashboard of both vehicles, which were similar to the CDF vehicles shown in Figure 24. The two vehicles started 100 feet apart and were instructed to proceed at approximately 1–2 miles per hour maintaining 100–200 feet of separation. The purpose of this was to simulate how CDF would position their vehicles to fight a brushfire where both vehicles would have firefighters walking in front of them on fire hose lines working the fire. The vehicles were to proceed westbound along the trail, which was along the crest of a ridgeline with occasional saddles until the trail intercepted the main road, at which point the vehicles would make a southerly turn and follow the main road back until it intercepted the trail that led up to the start point. The overview of the course is shown Figure 25.

Figure 23. CDF Vehicles

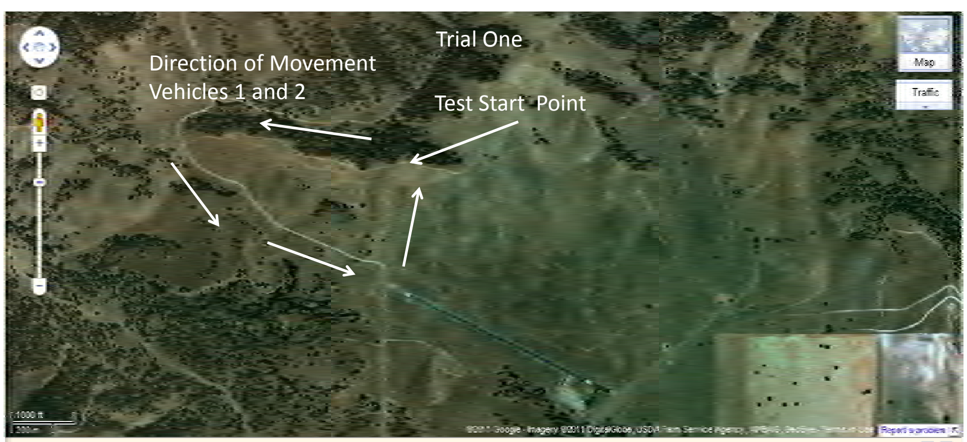

Figure 24. Overview of Trial 1 Route; Both Vehicles

2. Trial Two

For the second trial the configuration of the equipment remained the same in the two vehicles. This time, though, one vehicle proceeded as before, west along the ridgeline trail, but the second vehicle proceeded south along the trail towards the main road. Both vehicles again were instructed to maintain speeds of approximately 1–2 miles per hour. Once both vehicles met each other at the designated rally point, vehicle two turned around and proceeded via reverse course to the test start point. The overview of the Trial 2 route is depicted in Figure 26.

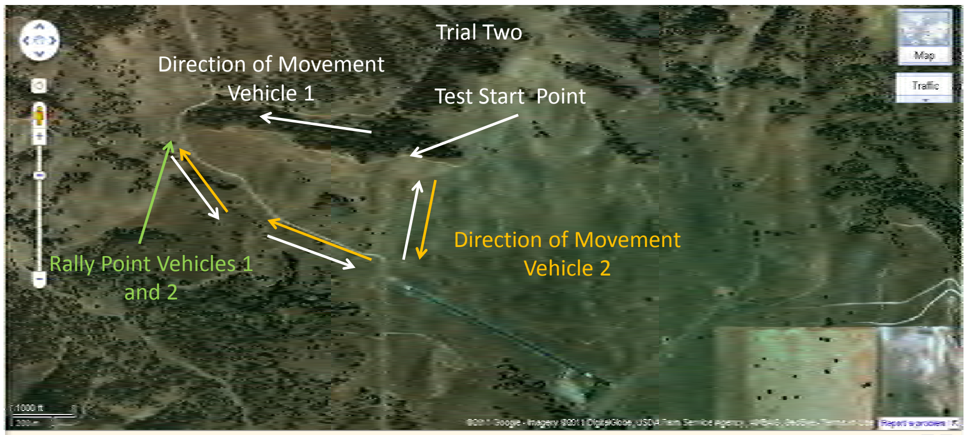

Figure 25. Overview of Trial 2 Route

3. Trial Three

The third trial conducted kept one Trellisware radio in each vehicle but the BlackBerry tag and Blackbird tag were placed in separate vehicles. This was done to test if the tags could be used to complement one another’s weaknesses. The BlackBerry and Blackbird tags, since they are cellular and satellite respectively do not require line of sight with the mobile command post and therefore the vehicles can continue to be tracked even when the Trellisware radio loses line of sight. The Trellisware radio, however, when it does have line of sight, is able to transmit voice and data, unlike the BlackBerry and Blackbird tags, which are only able to transmit location. The overview of the route used in Trial 3 is shown in Figure 27.

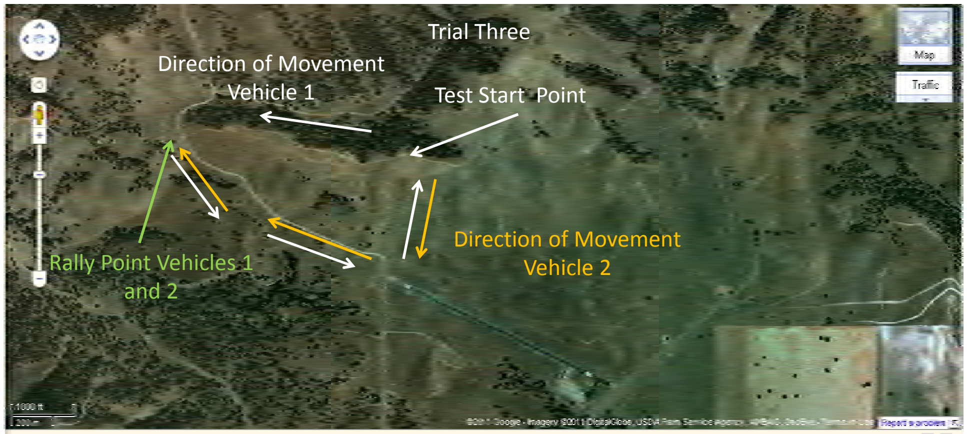

Figure 26. Overview of Trial 3 Route

D. EXPERIMENT ONE CONCLUSIONS

The results of the first experiment were extremely useful in furthering the research teams understanding of all three devices and the inherent benefits and shortcomings of each. Currently no single device has been able to overcome all the hurdles to become an all-purpose tag that will work in all terrain and all situations. A summary of the benefits and shortcomings of each type of tag is shown in Table 3. The BlackBerry device was rated the highest during the course of this experiment due to its quick refresh rate, but the test area had the benefit of a well-established cellular network. Combining the BlackBerry and Blackbird devices clearly offered the best solution, which is what the TerreStar device looks to achieve. This first experiment was conducted on short notice and without all the desired tagging and tracking assets. In the future at least two devices of each type should be used so that results can be compared between the two devices. Also more accurate timing is required to determine latency in the signal being relayed. During this first experiment two vehicles were used, moving at slow speeds, even slower than normal walking pace (2–3 miles per hour). Vehicles, ships, and aircraft all generally move at a much faster pace so experiments should be conducted with other types of vehicles to determine how accurately a position can be determined with each type of device. Cyber distortion effects were also not calculated due to the track points being accidently covered with a trend line, which showed the overall route taken but not the individually reported track points. For further testing the Trellisware radios will not be included in the experiment. They suffered the most from line of sight issues and required many more units in the area to provide sufficient coverage. While they would prove useful for friendly force tracking of units such as squads or firefighter crews with everyone equipped with a device, for covertly tagging equipment the radios would not be able to establish a network that would enable tracking of a single object. The radios are more adequately equipped for establishing mobile as hoc networks.

Type of Tag	Benefits	Shortcomings
BlackBerry	-Uses well established Cellular Network -Position Error displayed on device -High refresh rate < 5sec	-Will not work in areas without cell service
Blackbird	-Large satellite constellation in LEO results in limited LOS issues since usually have a satellite near Nadir -Works in austere environments not covered with cell service	-Bent pipe system means satellite must be in view of a ground station to complete transmission -No indication of accuracy of GPS position -Slow refresh rate >= 1 minute
Trellisware	-Can achieve high data rates -Capable of voice and data -Near-real time refresh	-Limited by line of sight

Table 3. Benefits and Shortcomings of Devices Tested in Experiment 1

VII. EXPERIMENT II

A. EXPERIMENT BACKGROUND

The second experiment conducted into the use of TerreStar for tagging and tracking was conducted as part of the Tactical Network Topology 11-4 Experiment. This experiment, similar to the TNT 11-3 experiment was also conducted at Camp Roberts. This experiment was conducted on 9 August 2011. The original goal of the experiment was to test four devices, two of which had been previously tested as part of Experiment 1, the BlackBerry messenger tag, and the Blackbird GPS tag. The two new tags to be tested consisted of the TerreStar integrated cellular/satellite phone, and a tag currently under development by DeLorme, which develops GPS based equipment. Since the BlackBerry messenger tag and the Blackbird GPS tag have been discussed in Chapter VI they will not be covered again here. The two remaining tags, however, will be discussed in more detail.

1. TerreStar Tag/Smartphone

The TerreStar device is the GENUS Smartphone, and is shown in Figure 28. The phone operating system is Windows Mobile 6.5 and has a touch screen and applications similar to what can be found on any other smartphone such as a BlackBerry or iPhone. The applications are downloadable from the Windows Marketplace. The phone is equipped with a USB connection so that it can be plugged into a computer and data transferred between the phone and a computer. The phone has an internal patch antenna for communication with the TerreStar-1 satellite. For use in areas where satellite coverage is weak there is an attachable external antenna. The phone configured with and without the external antenna is shown in Figure 28.

Figure 27. TerreStar Phone with and without External Antenna

For purposes of Experiment 2 the two devices that were available for test were not devices purchased by the Naval Postgraduate School research team. Those phones had not arrived in time for testing. The phones used for testing therefore were on loan from the TerreStar Corporation. As a result the phones could not be fully integrated into the NPS CENETIX Lab SA Agent. This presented a unique challenge for the research team since they now had to find a way to track the phones since a unique application could not be written in sufficient time to allow for the test and the loaned phones could not be modified. The solution reached was to use an application called Glympse. This application allows a user on a GPS enabled device to share their location through the use of a web-based map. An OV-1 diagram of how this enabled a viewer in the TOC to view the location of the TerreStar devices is shown in Figure 29.

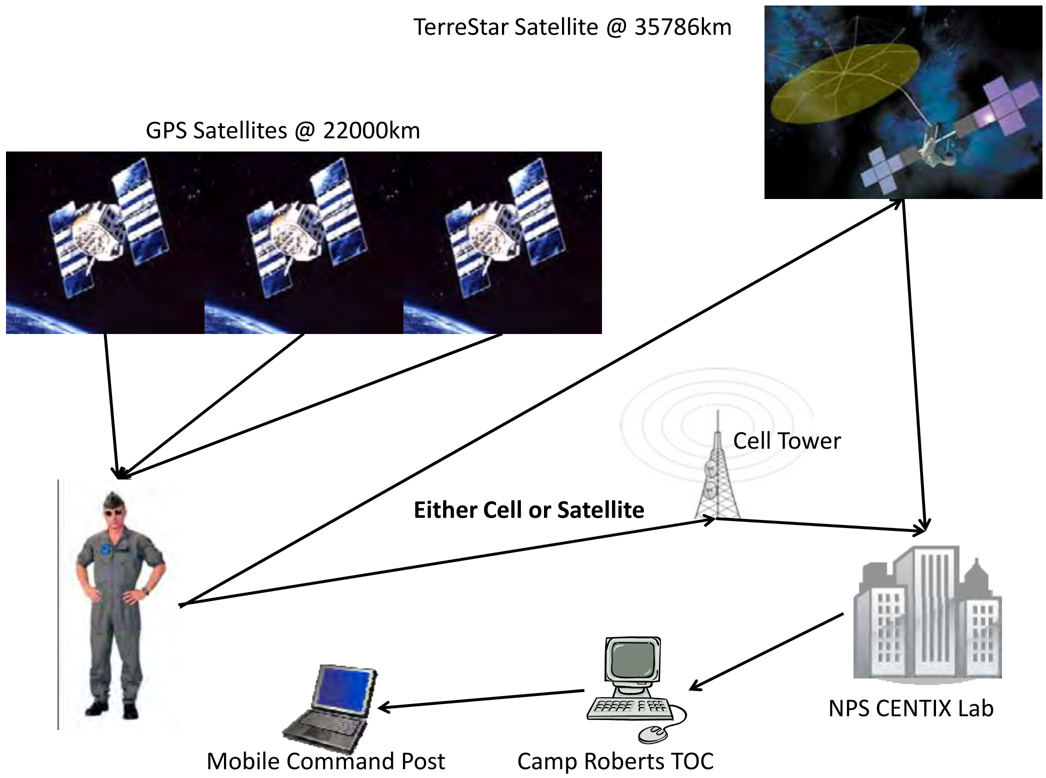

Figure 28. OV-1 Diagram for TerreStar Satellite for Experiment II

2. DeLorme Tag

The DeLorme tag is a tag currently under development by the DeLorme Company for commercial and government use. The tag is GPS enabled and works with the Iridium satellite constellation. No image is available for this tag. The tag works by transmitting position, a preset message, or a distress message over the Iridium constellation. The device can be paired using Bluetooth to another device such as a smartphone enabling full two-way communication. The tag can receive a message over the Iridium constellation and then using the Bluetooth connection to a smartphone transmit that message, either via text or e-mail. The system also works in the reverse direction, where the user can type in an e-mail or text and then using the Bluetooth connection link to the tag, which will then transmit over the Iridium constellation to the user at the other end. An OV-1 diagram of the system is shown in Figure 30.

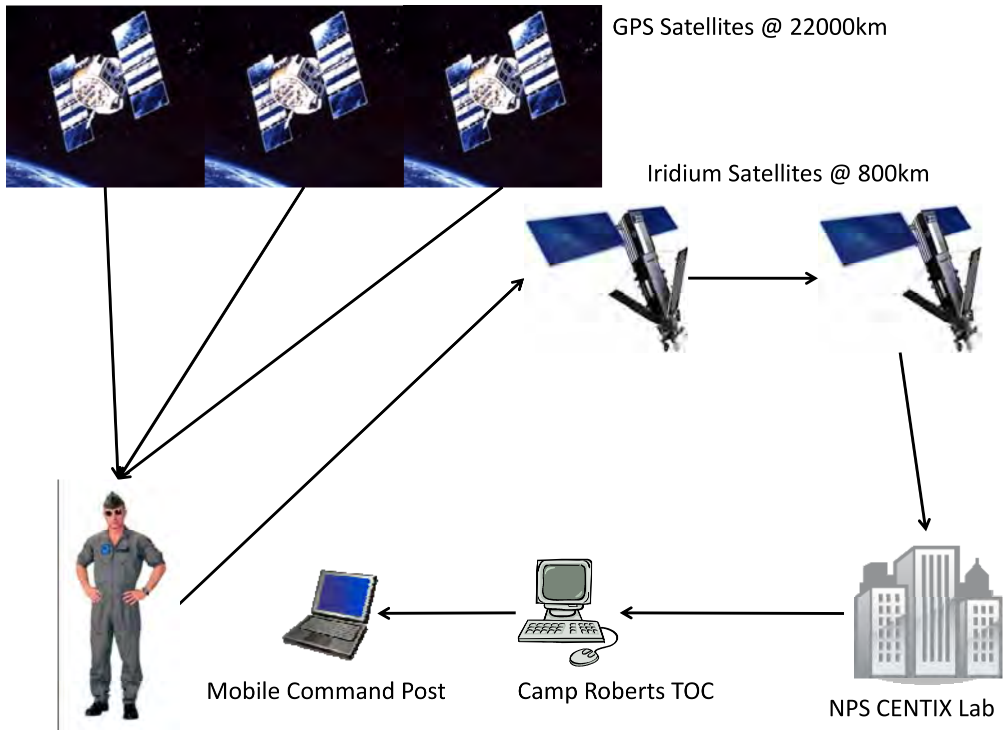

Figure 29. OV-1 Diagram for DeLorme Tag for Experiment II

The Iridium constellation is a constellation of 66 satellites in Low Earth Orbit that provides global coverage for satellite communications from an altitude of approximately 800km. In addition to the 66 satellites in use there are several in orbit spares. The satellites operate in the L-Band of the frequency spectrum for communication with customers using Iridium based satellite phones. Unlike GlobalStar, which only provides worldwide coverage, Iridium, as previously stated, provides global coverage. The difference between worldwide and global coverage is not insignificant. Global coverage covers the area primarily between 70 degrees north and south Latitude while worldwide coverage includes latitudes above and below 70 degrees to include the poles. Another significant difference between Iridium and GlobalStar is that Iridium can complete a call completely from orbit using Ka-Band satellite crosslinks. GlobalStar needs to transmit from the satellite to a Gateway station in order to complete the call on a terrestrial based network.

B. LOCATION OF TEST AND PARTICIPANTS

As previously stated, the test was conducted on board Camp Roberts, California, on 9 August 2011, as part of the TNT 11-4 Experiment. Similar to Experiment 1 the test was conducted in the vicinity of McMillan Army Airfield. The terrain and vegetation were consistent with the terrain and vegetation described for Experiment 1. Overviews of the test site can be referenced in Figures 18 and 19 from Chapter VI.

The participants, similar to Experiment I, consisted of thesis students from the Naval Postgraduate School and members of the California Department of Forestry and Fire Protection and the California National Guard. Two members of the California National Guard were also present to help provide personnel to conduct the tests. Vehicles were provided by the CDF, NPS, and the National Guard.

C. CONDUCT OF THE EXPERIMENT

Prior to the conduct of the experiment, since the exact location from which the trials would be conducted was not known, the TerreStar research team performed a brief analysis of the terrain throughout the southern Camp Roberts area. The team determined the look angle that would be required for communications with the TerreStar-1 satellite to see if there were any areas where line of sight to the satellite would not be possible. Equations 1 through 6 summarize the process used to determine the required azimuth and look angle. The radius of the Earth used was 6378km and the Geosynchronous orbital altitude used was 35786km. Once the required look angles were determined by hand they were compared with computer generated results. The results were also input into a website called Dishpointer, which computes azimuth and look angle data and then visually represents Line of Sight (LOS) to the TerreStar-1 satellite in GoogleEarth. Figure 31 depicts a Dishpointer image for several different locations in the vicinity of the Camp Roberts TOC to determine if there would be line of sight issues in the steepest terrain available at Camp Roberts.

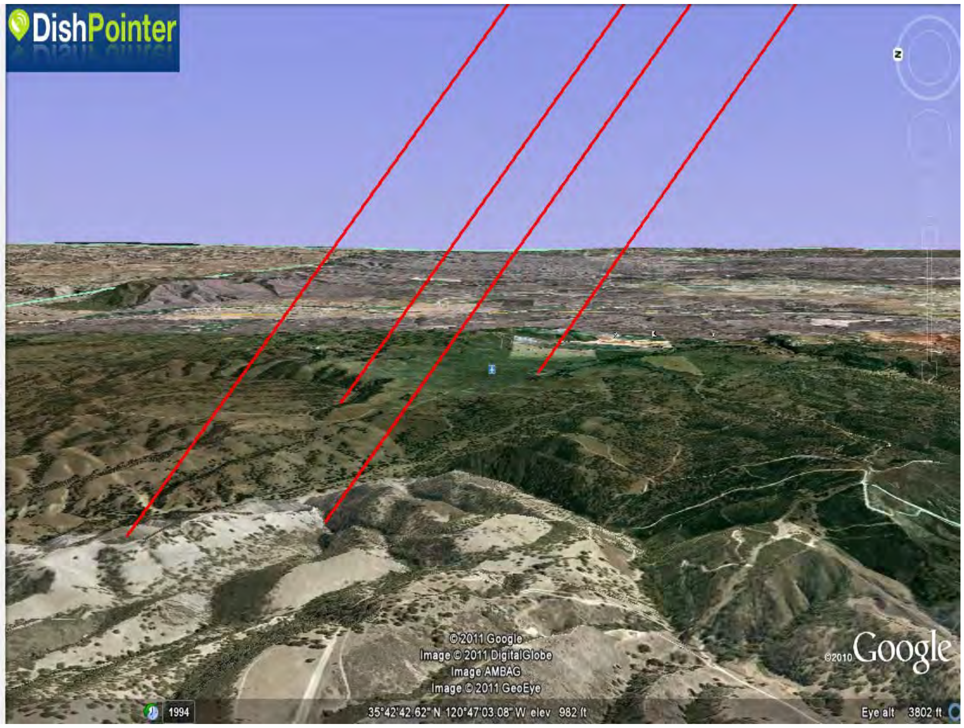

Figure 30. Test Points at Camp Roberts to Determine Line of Sight Issues in Available Terrain

Table 4 summarizes maximum and minimum LOS angles to the TerreStar-1 satellite based on the TerreStar-1 Satellite inclination of 6 degrees and orbital slot of 111W, and the Latitude and Longitude in the general vicinity of Camp Roberts, which for purposes of solving Equations 1 through 6 was -121W 35.8N.

(0.1) $$\sin\rho = \cos\lambda_o = \frac{R_E}{R_E + H} = \frac{6378km}{(6378+35786)km} \Rightarrow \rho = 8.7^{\circ}$$

(0.2) $$\Delta L = \left|L_T - L_s\right| = \left|249^{\circ} - 239^{\circ}\right| = 10^{\circ}$$

(0.3) $$\begin{aligned}&\cos\lambda = \sin\delta_S \sin\delta_T + \cos\delta_S \cos\delta_T \cos\Delta L\\ &\Rightarrow \sin 0 \sin 35.8 + \cos 0 \cos 35.8 \cos 10 \Rightarrow \lambda \cong 37\end{aligned}$$

(0.4) $$\begin{aligned}&\cos Az = \frac{(\sin\delta_T - \cos\lambda \sin\delta_S)}{\sin\lambda \cos\delta_S} = \frac{(\sin 35.8 - \cos 37 \sin 0)}{\sin 37 \cos 0}\\ &\Rightarrow Az = 13.6^{\circ}\end{aligned}$$

(0.5) $$\tan\eta = \frac{\sin\rho\sin\lambda}{1-\sin\rho\cos\lambda} = \frac{\sin 8.7\sin 37}{1-\sin 8.7\cos 37}$$
$$\Rightarrow \eta = 5.9$$

(0.6) $$\varepsilon = \cos^{-1}\left(\frac{\sin\eta}{\sin\rho}\right) = \cos^{-1}\left(\frac{\sin 5.9}{\sin 8.7}\right) = 47.2°$$

Inclination (degrees)	**λ (Earth Central Angle in degrees)**	**η (Nadir Angle in Degrees)**	**ε (Look Angle in degrees)**
6	31.2	5.1	54.0
3	34.1	5.5	50.7
0	37.1	5.9	47.2
-3	39.9	6.3	43.5
-6	42.8	6.6	40.6

Table 4. Minimum Line of Sight Angles to TerreStar-1 from Camp Roberts

The Experiment began with a brief at 0930 local time to cover desired objectives, number of trials to be conducted, order of the trials, and location of the trials. CDF desired a different route then the previous experiment so as to highlight differences between Experiment I and Experiment II. The TerreStar team's goal was threefold; first to establish that the method of tracking chosen would work in the local area, then to test how well the devices worked on their own, and finally to compare accuracy and latency between TerreStar and the other three devices being tested. The research team decided that the same general area as Experiment I would be used to conduct the test although routes used by the participants would vary from Experiment I. Second, it was decided that three trials would be conducted; each expected to last between 20 and 30 minutes.

The three trials would each consist of two personnel on foot taking different routes from a designated start point proceeding downhill to a designated end point. During each trial each person would be equipped with a TerreStar tag and one of the three other tags to provide a comparison. The first trial would consist of TerreStar and BlackBerry tags, the second trial would consist of the TerreStar and Blackbird tags, and the third trial would consist of the TerreStar and DeLorme tags.

At 1000 local time, the research team proceeded out to the test area to set up and configure the test equipment. Upon arriving at the test site several problems were encountered and the test was not able to proceed as planned. The first problem encountered was with the Blackbird and BlackBerry tags. Even though both tags were turned on and showing good reception of the GPS signal and good transmission of their location through the network, neither type of tag was displayed on the NPS SA view. The second problem encountered was with the TerreStar tags. The research team determined that the problem with the TerreStar tags was not a problem necessarily with the tag itself, but with the method chosen to track it. The Glympse application is an internet based application and the maps that display on the device are not stored on the device. Therefore, when the team attempted to start the application it needed to transmit large amounts of data via the satellite connection. This proved to be difficult and due to the latency of a signal going to and from geosynchronous orbit the team believes the internet connection was timing out, however other network issues have not been ruled out based on the single trial. This problem was overcome by first connecting to the application over the cellular network and then transitioning to the satellite network. The research team believes if the device had been able to be fully integrated into the NPS SA agent that this would not have been an issue. These two issues combined resulted in the research team shifting the focus of the experiment to first simply being able to track the TerreStar device both with and without the external antenna, and secondly to track it in varying terrain at Camp Roberts. Due to time and battery life constraints only two trials were conducted.

1. Trial One

For the first trial the research team's goal was to simply be able to track the TerreStar device. Both TerreStar Genus handsets were configured with the Glympse application and connected to the satellite. One of the devices was also configured with the external antenna while the other device relied solely on the internal patch antenna. Figure 32 shows the placement of the two TerreStar devices on the research participants.

Figure 31. Placement of TerreStar Tags

As the figure shows, the tag with the external antenna was placed on the rear hip of the research participant with the external antenna placed upright. The tag without the external antenna was placed in the left front breast pocket of the research participant with the screen facing the body and the rear of the device with the internal patch antenna facing outwards. The research team member located in the TOC confirmed that the TOC was showing two devices, labeled NPS1 and NPS2 at the start location, which was the same start location used in Experiment I. NPS 2 was the device configured with the external antenna. NPS 1 proceeded along the crest of the ridgeline and NPS 2 proceeded down the hill. Figures 33 and 34 show the two tracks achieved during this trial.

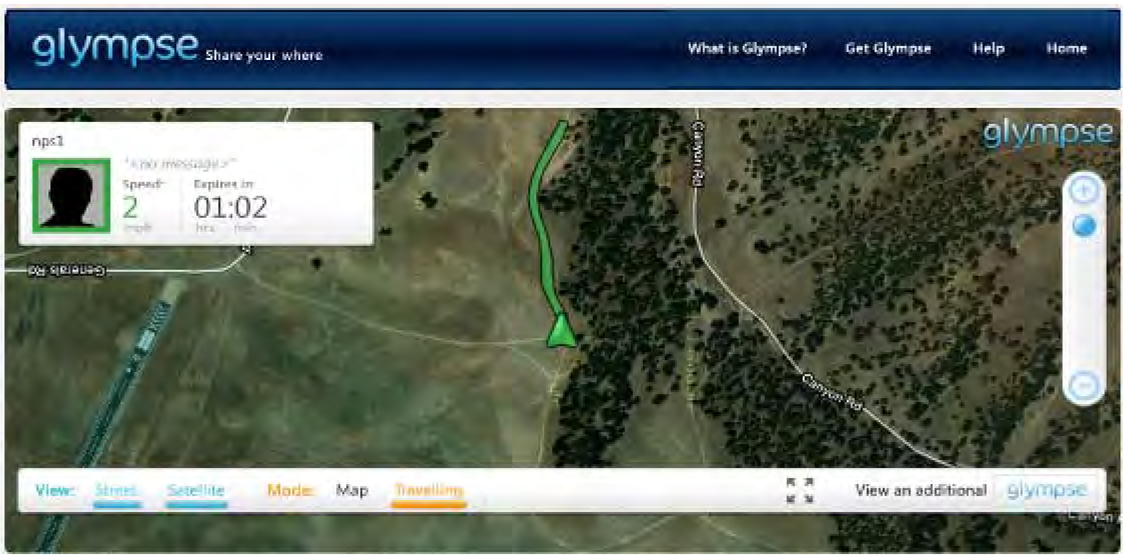

Figure 32. NPS1 Track for Trial 1

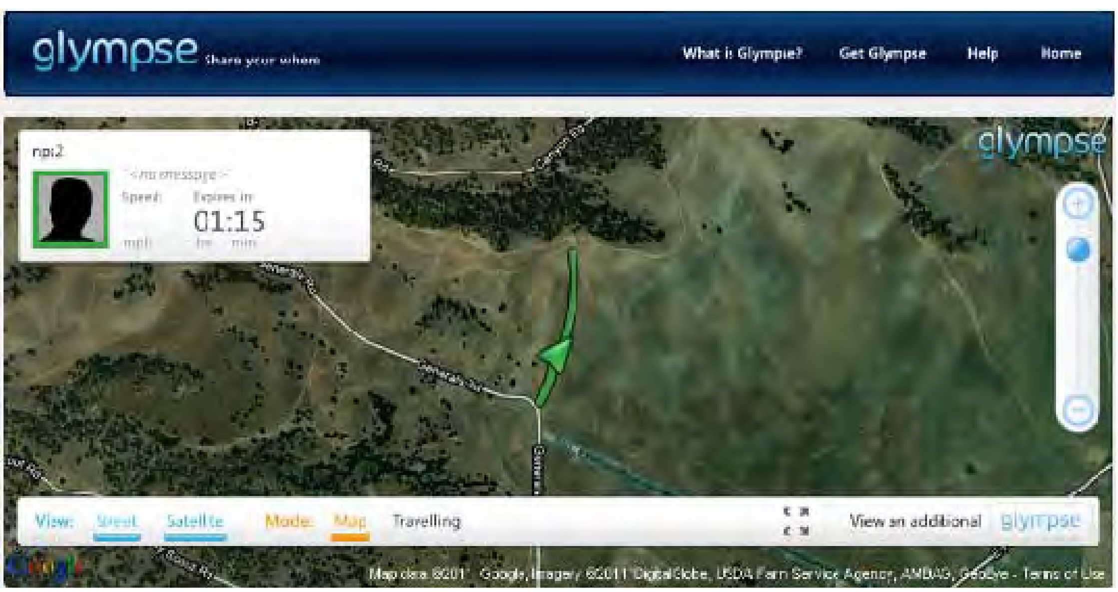

Figure 33. NPS2 Track for Trial 1

In the upper left hand corner of both tracks it shows that, when possible, speed can also be displayed. Although neither Glympse image shows the signal latency, that information is also displayed in the upper left hand corner when available. Over the course of the trial, the system indicated that it was updating the position anywhere between every 5 seconds and every 1 minute. One advantage of the Glympse application is that the color of the track will change depending on the length of time since the last update. This would be very useful if integrated into the NPS SA application. When CDF is attempting to track firefighters, Special Operations Forces are attempting to track a target or Homeland Security is trying to track special materials they would know if the tracks they have are old tracks or if they are still receiving an accurate, up to date track. This is exactly one of the problems identified in the TNT-MIO 10-2 Final Report Lessons Learned section, where it states,

> Highly trained operators of both Teams A and B experienced difficulties with target and search team dislocation on-the-move. Their recommendations include: the color display for the status of last know position should have read Green = recent/real time. Yellow = intermittent. Red = bad/ loss of connectivity. Additionally, the beeping on the short haul detection device should be muted (or be able to be muted) in a covert environment.

Knowing how old the track is can greatly change the strategy employed to track a target. When a search team believes they have accurate information they can limit their search to a specific area, but by changing the color of the track they know the information is not as reliable or accurate and can expand their search area accordingly.

The two tracks achieved during Trial One allowed the research team to verify that they could indeed track a target to within a few feet using the TerreStar device over the satellite connection. The next trial was used to see if that was a repeatable event using the in more difficult terrain.

2. Trial Two

The second trial conducted utilized the same start point as Trial One. This time, however, the research participant proceeded north from the start point down the backside of the hill that had much steeper terrain and would, at points, place terrain between the TerreStar device and the satellite. The tag utilized for this trial was NPS1 configured without the external antenna. The internal patch antenna was pointed away from the satellite, in the opposite direction, and placed the research participants' body in between the satellite and the device. The NPS2 tag, configured with the external antenna, was placed inside a standard SUV, on the dashboard, and the vehicle was driven along the ridgeline, similar to the path followed by NPS1 on foot, during Trial One. The two participant's planned directions of movement are shown in Figure 35.

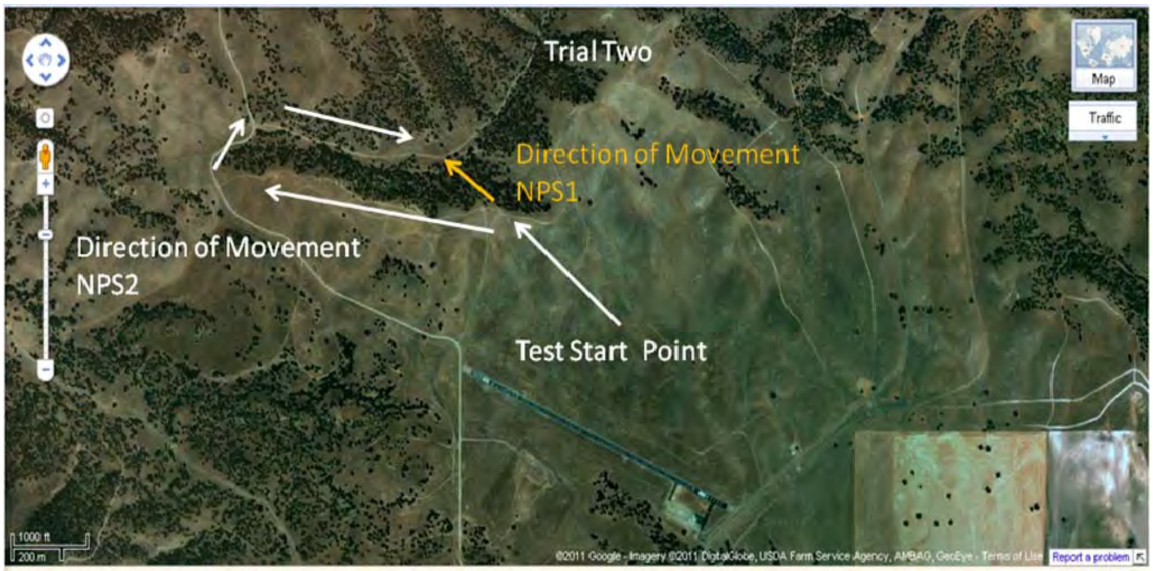

Figure 34. Trial Two Overview

The Camp Roberts TOC confirmed that it had two good target locations for NPS1 and NPS2 before the commencement of the trial. As soon as the trial started, however, the TOC informed the participants that it had lost the track on NPS2 and that the NPS1 track was no longer updating. The TOC began to troubleshoot the Glympse image while the research participants confirmed they had good satellite connectivity and that the TerreStar Genus devices where indicating that they were transmitting. After 10 minutes of troubleshooting in the TOC the research team was able to establish a track on NPS1 by refreshing the website every few seconds. No track could be established for NPS2. Two potential sources of the problem with establishing a track for NPS2 could be either the speed of the vehicle requiring a higher data rate since the vehicle was moving approximately 20 miles per hour and therefore the position needed to be refreshed more frequently as opposed to the 2 miles per hour the target on foot was moving, or a signal latency issue causing the Glympse application to go offline as was mentioned earlier with the problems getting the Glympse application to initialize over the satellite connection.

The track established for NPS1 is shown in Figures 36 and 37. Figure 36 shows a zoomed out overview of the overall route taken by the research participant, while Figure 37 shows a slightly more zoomed in view of the route taken. As both Figures indicate by tracks having turned to yellow the tracks are out of date tracks. Also, in the upper left hand corner it can been seen when the track was last updated. Features such as this, if added to the NPS SA agent tracker, could be useful in knowing where to search for a target, as stated in Trial One.

Figure 36 shows that the research subject had to vary his route in order to get around trees and other obstacles. Although this foliage was not dense the trees did represent a significant obstacle to establishing LOS with the satellite. The satellite signal was never lost though, as is indicated by the lack of breaks in the track.

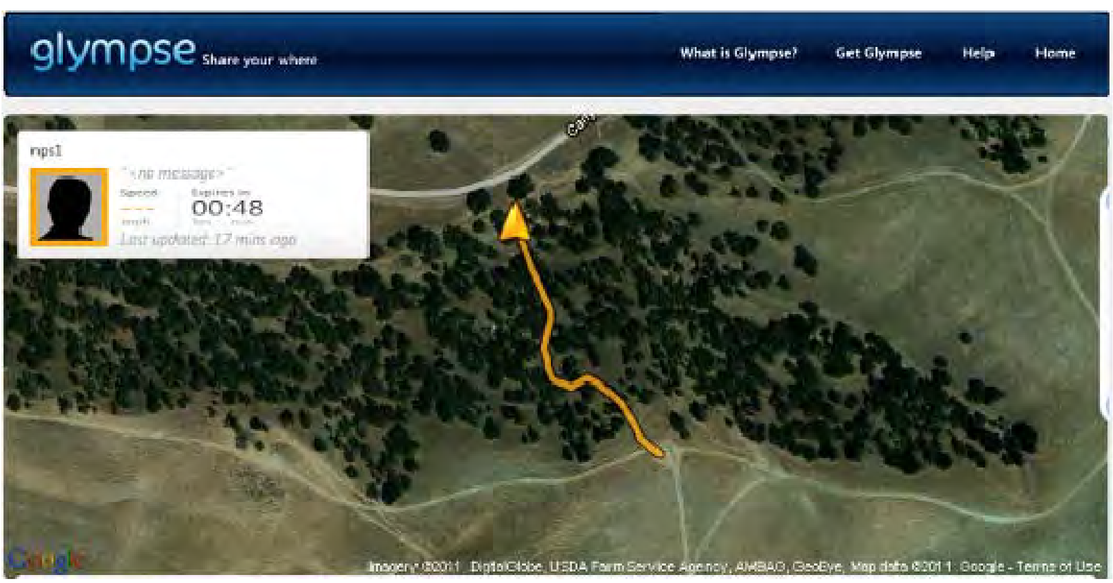

Figure 35. NPS1 Track from Start to Finish

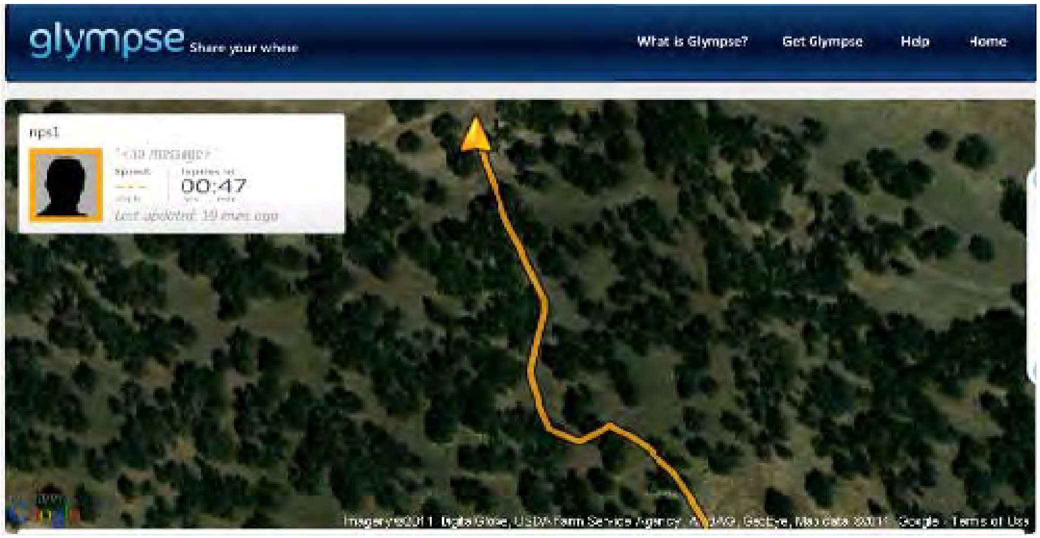

Figure 36. NPS1 Track Zoomed In

As part of the pre-experiment data analysis conducted to determine LOS issues between the TerreStar satellite and Camp Roberts, a point close to the end point of Trial Two was chosen. That point is shown in Figure 38. As can be seen from the figure, from the base of the hill there is no LOS issue from the terrain, but this does not take into account the trees that were present or the steepness of the grade going down the side of the hill. Figure 39 shows that based on a 0 degree inclination look angle of 47.1 degrees, at a distance of six feet from an object, that object can be no taller than 6.5 feet before it blocks the Line of Sight to the satellite. Using this same computation, any obstacle clearance can be determined.

Figure 37. Dishpointer Analysis of LOS of Trial Two Endpoint

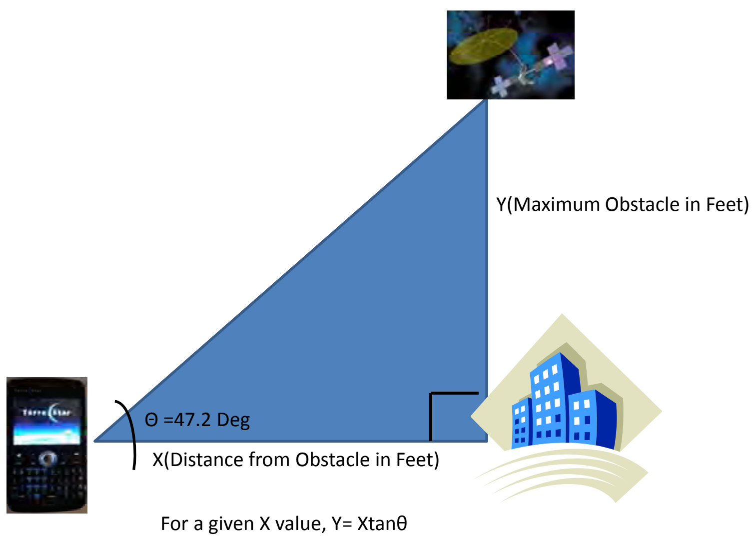

Figure 38. Maximum Obstacle Height

D. EXPERIMENT II CONCLUSIONS

Experiment II, while not meeting the original objectives of the planned experiment, still proved valuable to the research team. First, the team was able to show that using either the internal patch antenna or external antenna attachment the satellite link could be established and transmit tracking data. Secondly, even in the presence of obstructions to the LOS such as terrain, personnel, and the antenna intentionally being misdirected the link could be completed. Further integrating the devices into the NPS SA system should allow for a better tracking capability. Although TerreStar advertises up to a 400kbps data rate the research team viewed the primary problems encountered were not a function of sufficient satellite coverage/LOS issues but rather of data rate, which was unexpected.

This experiment also gave the research team hands on practice with the devices and some of the problems encountered may be overcome with additional experience working with the tags. For example, several times unfamiliarity with the functions caused the external antenna, while attached, to not be used. Also, there were several occasions when sending a Glympse the program was exited and had to be restarted, slowing down the process. As the devices are integrated into the NPS SA agent and the research team becomes more familiar with the devices these problems will go away.

One of the largest shortcomings identified in the TerreStar devices is the short battery life. When conducting standard voice calls over the cellular network, the battery life is approximately 4 hours of continuous voice communication. Once the phone is transitioned to satellite mode the maximum available battery life is reduced to 1.5 hours. This makes the phone useful for short duration tagging, but limits its effectiveness for long term tagging.

Cyber distortion affects were not sufficiently gathered during this experiment to warrant analysis. The tracks captured range in update frequency from a few seconds to a minute. This provides “near-real time” tracking data, but if an agency is trying to track a vehicle in heavy traffic or in a city this level of near-real time may not be sufficient to track vehicles turning down different streets in adequate time to provide notification to a vehicle conducting surveillance to make the same turn.

Although this test was similar to the first experiment it provided a baseline so that all the devices were initially tested in the same environment and terrain. Unfortunately due to time constraints the TerreStar device could not be compared directly with the DeLorme tag. Both tags use satellite systems and enable messaging with the device, and future work should compare the two devices to see if there are benefits in the way DeLorme has packaged their tag with a Bluetooth connection to another device, or if the all in one package of the TerreStar Genus phone is a better fit for the needs of CDF, Homeland Security, and other government agencies. Therefore, this test was not able to eliminate any device from future testing, but merely established the capability of the TerreStar device to establish a track and function as a tag.

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VIII. EXPERIMENT III

A. EXPERIMENT BACKGROUND

The third experiment conducted looked only at the TerreStar Genus smartphone, and was not conducted as part of a larger experiment as was the case for Experiments I and II. This experiment was conducted in the vicinity of Monterey, CA, on 11 August 2011. The goal of this experiment was to test the TerreStar device in different terrain than was encountered at Camp Roberts. Camp Roberts, although it had some slight hills of 100 to 150 feet in height, and sporadic tree cover, provided for the most part, ideal conditions for the TerreStar device. A secondary goal of this experiment was to test the TerreStar satellite's ability to track a vehicle moving at varying speeds as would be the case if the vehicle was being targeted for tracking by a law enforcement agency for interception.

B. LOCATION OF TEST AND PARTICIPANTS

This third and final experiment was conducted in the vicinity of Monterey. Monterey and its surrounding area was chosen because of its dense foliage cover, and difficult coastal terrain with several large and steep hills of several hundred feet. The difficulty of the terrain and tree cover was expected to put a strain on the ability to complete the link with the TerreStar-1 satellite. This was viewed as an incremental step before testing the device in an urban setting and on coastal police boats operating from near shore, where cellular networks would be available to well offshore where satellite communications would become necessary.

C. CONDUCT OF THE EXPERIMENT

As stated previously the experiment was conducted on 11 August 2011, in the vicinity of Monterey. The single test involved the use of both available TerreStar Genus devices. One was configured in the cellular mode and the second was configured in the satellite mode with the attached external antenna. The cellular configured device was placed on the dashboard of the vehicle as shown in Figure 40. The satellite device was attached on the driver side door using zip ties to the hand hold as shown in Figure 41. The Glympse application, used previously in Experiment II, was then started on both devices. Once it was confirmed that both devices were being successfully tracked by computer at the Naval Postgraduate School the trial began. Only one trial was conducted due to time constraints with the necessity of both devices being returned to TerreStar that day and with the expiration of the SIM cards provided by TerreStar.

Figure 39. Cellular Configured TerreStar Phone for Monterey Trial

Figure 40. Satellite Configured TerreStar Phone for Monterey Trial

The vehicle proceeded along Camino Aguajito from 5th Street until it reached Del Monte Avenue at approximately 20–30 miles per hour. Upon reaching Del Monte Avenue the vehicle turned right and proceeded along Del Monte Boulevard until reaching Canyon Del Rey Boulevard. Traffic flow ranged between 5 miles per hour and 40 miles per hour during this time. At Canyon Del Rey the vehicle was stopped at the light for several seconds and at this point the satellite signal was lost. Figure 42 shows the track of the satellite configured TerreStar phone from the start of the trial until loss of the satellite track at the turn onto Canyon Del Rey. Although the device indicated that the satellite link had not been lost the research team believes that the internet application timed out as had happened at Camp Roberts during Experiment II due to signal latency and a low data rate. One possible reason for this is a large building located on the corner of Del Monte Boulevard and Canyon Del Rey. The LOS to the TerreStar satellite from this location is shown in Figure 43. The LOS is completely obstructed from the intersection due to the building, and while the phone indicated it still had a satellite link the link may have been degraded enough as to prevent use of the internet.

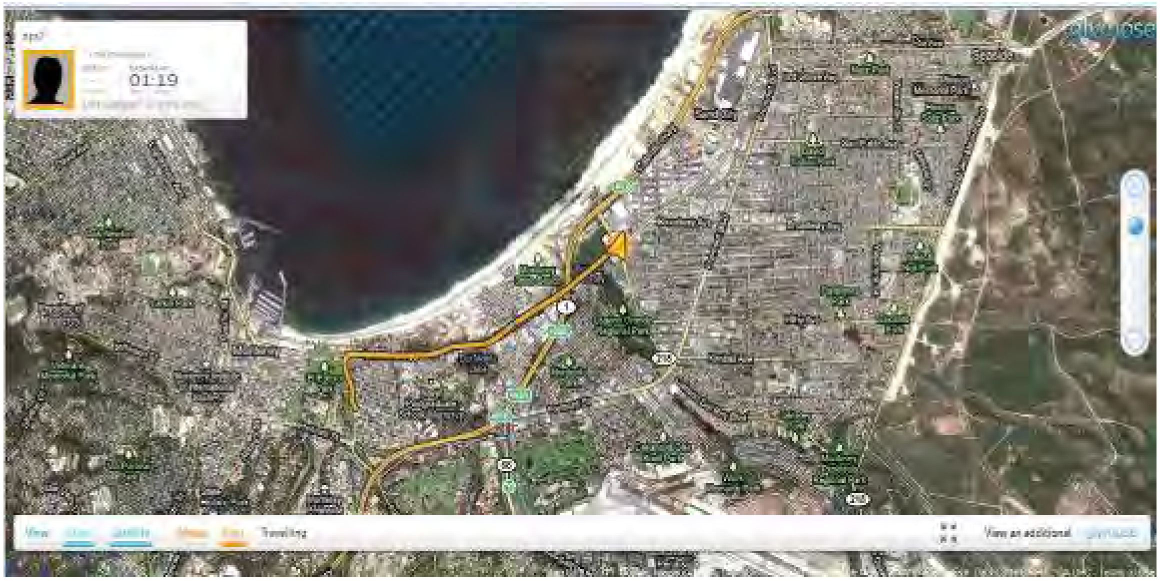

Figure 41. NPS2(Satellite Configured) Track for Monterey Trial

Figure 42. LOS to TerreStar from Del Monte Blvd / Canyon Del Rey Intersection

The trial continued by proceeding southbound on Highway-1 at speeds between 30 and 70 miles per hour. Several attempts were made to restart the Glympse application during the rest of the trial on the satellite configured device but were unsuccessful. The trial continued southbound on Highway-1 and then in the vicinity of Carmel Valley the vehicle turned around and returned northbound on Highway 1 until reaching Camino

Aguajito at which point the vehicle exited the highway and returned to the start point. The entire route taken is shown in Figure 44.

Figure 43. NPS1(Cellular Configured) Track for Monterey Trial

D. EXPERIMENT III CONCLUSIONS

The goal of Experiment Three, specifically to test the TerreStar device in different and more challenging terrain was successful. The research team viewed some of the shortcomings noted, and difficulty in tracking the device to be the result of the internet enabled application. At no point did the device indicate that it had lost the satellite signal even when LOS was obstructed by a building, trees, terrain, and being placed inside a vehicle. The research team believes that the connection and data rate may have slowed but not stopped which resulted in the internet enabled application timing out although further investigation needs to be conducted to verify if this is the case and equipment will need to be used to monitor the data rate. Figure 45 shows a combined overlay of both the satellite enabled and cellular enabled TerreStar devices. Although this trial used two devices to get one combined track it shows the advantage of having one device capable of being configured for cellular or satellite. The current TerreStar device is not capable of automatically switching between cellular and satellite but must be switched manually.

This is not a technology limitation but instead one placed on TerreStar by AT&T. AT&T is the company which sells the satellite service on behalf of TerreStar which owns and operates the satellite. AT&T wanted customers to realize they would be using the satellite and be incurring charges for using the satellite and therefore make a conscious decision to do so. (TMF Associates, 2009) Future devices can be designed to automatically switch. This trial did show that a vehicle could be successfully tracked using the TerreStar device, although this trial did require two devices to maintain a track; if a device was configured to automatically switch between cellular and satellite only one device would have been required to maintain a successful track. This vehicle could have been tracked through urban and more rural terrain and at speeds ranging between 5 and 70 miles per hour.

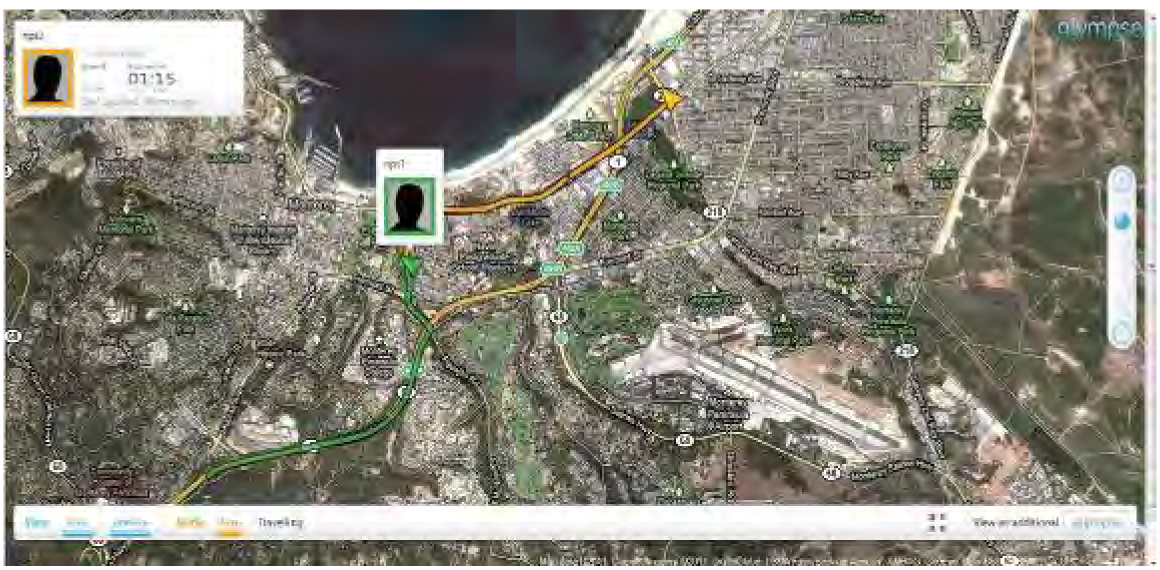

Figure 44. NPS1 and NPS2 Combined Track for Monterey

IX. CONCLUSION

A. SUMMARY

Recent improvements in technology enable the warfighter and commander to know the exact location of Joint forces and hostile Red forces using a space-based satellite tracking system. This development increases situational awareness in a combat environment. This kind of capability is not only important for a battlefield commander but also homeland security and firefighter commanders. A review of current and legacy tracking systems has been conducted in order to provide the most accurate and necessary information to personnel who could require a friendly force tracking system. This review evaluated the capabilities of the TerreStar constellation for real-time situational awareness to include the following: Blue/Red Force Tracking, operations and monitoring of special event boundaries in and around urban canyon locations and underserviced areas traditionally covered by the Global Positioning System-based tracking systems. This study also included research into tagging a small craft or vehicle that is suspected of carrying illicit/nonproliferated materials, locating it, and tracking its global movement. Lastly, this research included an evaluation of the effects of cyber distortion on tagging and tracking.

B. RESULTS AND ANALYSIS

Over the course of the three experiments conducted one satellite only solution was tested (GlobalStar based Blackbird), one cellular only solution was tested (Blackberry based tag), and one combined cellular-satellite tag (TerreStar based GENUS). Devices such as the Trellisware radio were also initially tested and plans were made to test another satellite based system (Iridium based DeLorme) however due to logistical constraints the DeLorme tag was not tested.

The GlobalStar based Blackbird tag achieved a 100% success rate during the two experiments at Camp Roberts during which it was employed. Whether placed in a vehicle or personnel mounted it never failed to achieve a connection to the GlobalStar network and transmit its location back to the network. The only time the GlobalStar device failed to work was when indoors, and this was not during the conduct of the experiment and was not included in the test results. Although during the second experiment a track could not be conducted due to network errors there was no failure of the device in over 10 hours of testing. The device however had limitations that severely limited its usefulness. Specifically it was only a tag and had no data sending capability other than sending its location. Also, the tag had no display so the user could not verify how accurate their transmitted position was or display the tracks of other users. The minimum 1-minute time interval also limits its usefulness in certain environments, such as urban terrain.

The Blackberry tag also achieved a 100% success rate during the two experiments it was employed at Camp Roberts. Similar to the GlobalStar tag, during Experiment II, a track could not be established but, this was due to a failure of the NPS SA network, and not the device. There were several noted benefits of the Blackberry tag to include good indoor coverage, a user interface display, and a Figure of Merit indicator to let the user know how accurate the device was able to calculate position. Due to the good cellular network coverage on Camp Roberts there was no time when the device failed to work.

The TerreStar tag, when operated in the cellular mode, achieved a 100% success rate. The TerreStar device also achieved a 100% success rate for establishing an initial connection to the satellite. During the course of Experiments II and III over 20 attempts were made to connect to the satellite and all achieved a connection. Noted limitations of the TerreStar device was the short battery life when operated in satellite mode, and the suspected slow data rate. The slow data rate requires further investigation once the devices are integrated into the NPS SA client and the Glympse application is no longer necessary. The other major limitation of the current generation of TerreStar devices is the inability to automatically switch from cellular to satellite. If future iterations of the device become available it would combine many of the best features of the Blackberry and Blackbird tags/devices. Specifically the device would be able to function indoors were satellite access is not available and in remote locations not serviced by cellular networks. Also, as was noted during Experiment III when the device had LOS problems, such as buildings, the cellular capability would have been able to take over and maintain a track.

TerreStar provides a unique solution not previously available. There are many providers of Friendly Force Tracking technology in the current industry. However, the systems provided rely on either satellite systems or line-of-sight systems. TerreStar is the first provider to offer a combined satellite and cellular system. This provides a new method of tracking friendly forces or target subjects in North America. This technology could be extremely useful in a natural disaster scenario such as a hurricane, earthquake, or forest fire. In the case of either a hurricane or earthquake, the possibility exists that terrestrial cellular networks would be disrupted or overwhelmed. In this situation, it would be difficult to track first responders and ensure that search and rescue assets are properly deployed without a satellite-based network. In the case of a forest fire or wildfire, where both satellite service and cellular service could be disrupted, it provides a redundant path and therefore reduces the chance that tracking will be lost.

C. RECOMMENDATIONS

Further study needs to be conducted in several areas with regards to the applicability of TerreStar to tagging and tracking of both friendly forces and other targets. One of the areas of study is an analysis of the data rate over the cellular and satellite networks. While the GPS data does not require a high data rate, the goal is to transmit not only location data, but also additional data to include text, sensor data, and possibly images. The TerreStar network offers unique advantages not currently available by any other means for tagging and tracking and further study of its applicability to different situations is warranted.

D. FUTURE WORK

The research team had originally envisioned a different test schedule, and different tests then were eventually conducted. This was due to several factors, most notably the difficulty in obtaining the TerreStar handsets for testing. One of the original goals was to look at Maritime Interdiction Operations using the TerreStar handset as a tag, as a precursor to a more miniaturized TerreStar tag that would be a pure tag and not in the current smartphone configuration/packaging. The research team considers

TerreStar to be a viable option for conducting offshore tagging and tracking of suspect small craft entering and leaving U.S. ports especially once the ships are out of range of shore based cellular networks. Due to the delay in acquisition, testing of this nature was never able to be conducted. Once the devices are acquired testing of this nature should be conducted.

Secondly, again due to the delays in acquisition, the TerreStar device was never fully integrated into the NPS SA client. Doing so would allow for a more accurate and direct comparison between other types of tags, such as the Blackbird and BlackBerry tags, which have already been integrated. This would specifically eliminate using the Glympse application which was suspected of being one of the problems with the loss of tracks. Direct comparison between the three types of satellite tags, Blackbird, DeLorme, and TerreStar also still remains to be conducted.

Finally, the device has been tested in the relatively open terrain of Camp Roberts, and the more restricted terrain of Monterey. Expanding that test to nearby urban settings to see if TerreStar can successfully track using the satellite link would also be of value. This would allow tracking even if, for some reason, cellular networks were out of service or unavailable for another reason such as being overwhelmed. For example, during the September 11, 2001 attacks on New York the cellular network became so overwhelmed it could not handle any more traffic and for extended periods of time calls could not be completed. If NYPD and FDNY officers had been equipped with TerreStar type phones they not only would have been able to complete calls as necessary, but the police and fire command posts would have been able to better track the location and dispersion of their assets and allocate them more efficiently. In the event of this kind of terrorist attack or any other special event, such as a natural disaster accurately knowing distribution of assets is critical and further research should be conducted to evaluate TerreStar's applicability to this field.

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